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EXPANSION OF STEAM IN THE STEAM-ENGINE.

An Investigation of the Experiments made with the Screw Machinery of the French Naval Steamer CHER *to Determine the Economic Efficiencies of Different Measures of Expansion for Steam.*

By Chief Engineer ISHERWOOD, U. S. Navy.

In the month of February, 1866, the experiments whose data and results are given in the following table, were made with the machinery of the French Naval Steamer *Cher;* the vessel being held stationary in the basin of the Naval Arsenal at Cherbourg, while the machinery was operated; the power developed by the engine being applied to the displacement of water by the screw.

These experiments were made by very distinguished engineers of the French Navy; they were conducted by Messrs. Joessel and Thibaudier, under the supervision of Mr. Moll, and had for their main object the determination of the relative economic efficiencies of the different measures of expansion with which the steam was used under the

experimental conditions; they were undertaken as a test of the results of the well known experiments made by the writer for the same purpose with the paddle-wheel machinery of the United States Steamer *Michigan*, at Erie, in 1860 and 1861, the vessel in this case having been also held stationary at the dock while the machinery was in operation.

The writer's experiments on this subject preceded, by a number of years, all others, and he was the first to show the quickly reached limit of the economic gain due to increasing measures of expansion, and the causes determining that limit, the principal of which was the rapidly increasing cylinder condensation which accompanied the increasing measures of expansion. He first showed that steam, instead of being a gas and governed by the ideal laws of such a substance, was the most unstable of vapors; that the abstract law of Mariotte had a limited concrete application to it, and that its economy was mainly controlled by the physical conditions of its use, such as the heat-absorbing, and heat-imparting power of the iron cylinder subject to great variations of temperature on its inner surface during a double stroke of the piston, and also of the back pressure against the piston of the uncondensed vapor, when the problem was conditioned for equal initial cylinder pressure, speed of piston and power developed, the space displacement of the piston per stroke being necessarily variable with the measure of expansion employed for the steam, larger measures of expansion requiring larger cylinders. These conditions gave for the increasing measures of expansion, a decreasing mean pressure per square inch of piston, while the back pressure continuing constant per square inch of piston, became a larger and larger proportion of the mean pressure (measured from zero) as the measure of expansion became greater and greater. It was obviously only necessary to carry the expansion far enough with any constant back pressure, to make the latter nearly balance the mean pressure, and the external work of the engine would be reduced to nothing, its whole power being employed in overcoming its friction and the back pressure against its piston. The back pressure, therefore, reduced the commercial economy of the steam more with the greater than with the less measures of expansion. The same observation applies to the pressure required to overcome the friction of the engine, *per se*, that is, to work it unloaded. This pressure per square inch of piston, like the back pressure, is nearly constant, and it is only the remainder of the mean pressure above

zero after the subtraction of both, that is commercially useful in doing external work. The friction pressure, therefore, still further limits the measure of beneficial expansion.

From the foregoing it is obvious that a proper comparison of the commercial economy due to various measures of expansion, requires the *net* power developed by the engine in each case to be compared with the cost of producing it in fuel, or more accurately with the number of units of heat in the boiler steam required to produce it, the net power being the power due to the mean pressure on the piston above zero, less the back pressure and the friction pressure.

The waste spaces in the clearance of the piston, and in the steam passages, also limit the measure of beneficial expansion; first, by the heat-absorbing and heat-imparting nature of the inner metallic surfaces, for they experience the same changes of temperature as the inner surface of the cylinder; second, by the steam required to fill these waste spaces, which is greater, proportionally to power produced, with larger than with smaller measures of expansion.

The combined effect of all the foregoing causes, under the conditions stated, is found experimentally to limit the commercially beneficial measure of expansion for saturated steam of not more than 25 pounds pressure per square inch above the atmosphere, used in condensing non-compound engines without steam-jacketed cylinders, to what is due to cutting it off when the piston has completed 0·6 of the stroke of its piston, being equivalent to an expansion of about one and a half times. With higher steam pressure, with superheated steam and with steam-jacketing, the foregoing causes become proportionally less, and the beneficial measure of expansion increases; but it is very doubtful if any gain can be obtained with practicable pressures and superheating beyond what is given by an expansion of about three times, and the difference in the economic results between expansions of one and a half and three times, is not large.

The writer also first showed that when steam was used expansively, the cylinder acted both as a condenser and a boiler: as a condenser during the portion of the stroke of the piston preceding the closing of the cut off or expansion valve, and as a boiler during the remaining portion of the stroke; part of the water of condensation deposited on the cylinder surfaces during the first portion of the stroke, vaporizing during the last portion by its contained heat and the heat of the metal of the cylinder under the continuously decreasing pressures due

to the continuous expansion of the steam. Whatever water of condensation remained when the piston reached the end of its steam-stroke, vaporized during its exhaust-stroke under the still lower condenser pressure, so that when the steam-valve again opened to admit steam from the boiler to the cylinder, the whole of the steam which had been condensed in the latter had been re-evaporated and passed over into the condenser.

The writer not only stated these facts qualitatively, but gave, by means of his experiments, very exact quantitative measures of the per centum of the steam evaporated in the boilers condensed in the cylinders prior to the closing of the expansion-valve, and the per centum of the steam vaporized in the boiler present in the cylinder at the end of the stroke of the piston; the difference between the two per centums showing the amount of the re-vaporization after the closing of the expansion-valve above any condensation which might have occurred during the expansion portion of the stroke.

It would seem that no great difficulty should have been found in accepting the experimental facts first published by the writer in this connection, particularly as they admitted of easy confirmation by a few rough trials with almost any engine: nor in perceiving that the discrepancies between them and what ought to have been obtained according to the ideal law of Mariotte, were due to the causes he discovered; yet the facts and the deductions were violently impugned in both America and Europe, but apparently with more of wounded vanity and alarmed interest than of philosophic spirit; they are now, however, accepted almost everywhere, and nowhere more completely than in France, whose steam engineers as a class are incomparably superior in scientific education to those of other nations. The problem is purely an experimental one, and does not require for its solution either mathematics or physical science, though both may be invoked to explain the solution after it is obtained. In this manner the problem was treated by the writer who put the question directly to nature under the conditions of ordinary practice, and received an infallible reply in the experimental results. The French engineers followed exactly his method, and obtained the same answer, as will be seen by the conformity of their results in the following table. Nor has the writer ever found different results, either in his own very numerous and carefully conducted experiments on a large scale, or in those of others.

In order that the scale on which the experiments of the *Cher* were conducted may be understood, the following dimensions of the machinery are given:

ENGINE.

There is one compound back action engine, of the kind known as the Depuy de Lôme type. It consists of three cylinders of equal diameter and stroke of piston, placed horizontally side by side; the steam from the boiler being admitted into only the middle cylinder, where it is cut off by lap on the main valve when the piston has completed 0·88 of its stroke. From the middle cylinder the steam is expanded simultaneously into the two end cylinders, where it is cut off by lap on the main valve when 0·78 of the stroke of the piston is completed. The steam is not cushioned in any of the cylinders. From each end cylinder the steam is exhausted into a surface condenser placed immediately opposite to it, and the two condensers are connected by a pipe at their top, so that the vacuum is the same in both, and the condensing surface in both is available for the steam from each end cylinder. These two cylinders are connected upon the same shaft by cranks at an angle of 90 degrees; and the middle cylinder is connected to this shaft at an angle bisecting 90 degrees, its crank making an angle of 135 degrees with those of the end cylinders. The cylinders are not steam-jacketed, except in so far as the passage is concerned by which the boiler steam is carried over each end cylinder to the middle cylinder. There is no separate cut-off valve on the end cylinders, but there was one on the middle cylinder arranged to close when the piston of that cylinder had completed the 0·4, 0·5 and 0·6 of its stroke.

The cylinder-valves were worked from cranks on a small shaft, placed immediately over the crank-shaft and receiving motion from it through spur-gearing of equal diameter, consequently the stroke of the valves could not be varied.

Each end cylinder worked a horizontal double acting air-pump and circulating-pump for its own condenser.

Number of cylinders, ...	3·
Diameter of each cylinder, ...	43·3079 in.
Stroke of the piston of each cylinder, . .	1·64045 ft.
Net area of each piston, exclusive of areas of rods,	1460·500 sq. in.

Space displacement of each piston per stroke, exclusive of rods,	16·638 cu. ft.
Aggregate condensing surface in both condensers,	1266·098 sq. ft.

BOILERS.

There are two boilers with horizontal return-tubes. Each boiler contains three furnaces of the same dimensions. Both boilers discharge their gases of combustion into one chimney, the base of which is occupied by a steam superheater composed of plates.

Number of furnaces,	6·
Aggregate area of grate furnace,	87·514 sq. ft.
Aggregate area of water-heating surface, calculated for the outside circumference of the tubes,	2249·525 sq. ft.
Aggregate cross area of the tubes for draught,	14·586 sq. ft.
Area of steam superheating surface,	212·703 sq. ft.
Square feet of water-heating surface per square foot of grate surface,	25·705
Square feet of steam superheating surface per square foot of grate surface,	2·430
Square feet of grate surface per square foot of cross area of tubes,	6·000

SCREW.

There is one Mangin screw with two pairs of blades, one pair being directly behind the other. The pitch expands gradually from the forward to the after edge of each blade. When the blades are viewed in projection on a plane parallel to the axis of the screw, their edges taper towards each other from the hub by straight lines, the length of the screw being greater at the hub than at the periphery. The central line of each blade is at right angles to the axis.

Diameter of the screw,	11·483	feet.
Diameter of the hub,	1·750	"
Initial pitch,	12·139	"
Mean pitch in function of surface alone,	13·452	"
Final pitch,	14·765	"
Number of *pairs* of blades,	2·	
Length of the screw in the direction of the axis at the hub,	1·8833	"
Length of the screw in the direction of the axis, at half the radius,	1·3452	"
Length of the screw in the direction of the axis, at the periphery,	0·8071	"
Fraction used of the pitch at the hub,	0·280	"

Fraction used of the pitch at half the radius, .	0·200	feet.
Fraction used of the pitch at the periphery, .	0·120	"
Mean fraction used of the pitch in function of surface and of the propelling efficiency of the surface,	0·162	"
Helicoidal area of the screw-blades, . . .	23·191	sq. "
Projected area of the screw-blades on a plane at right angles to axis, ...	18·460	" "

Experiments made on the Screw Machinery of the CHER *with the vessel held stationary at the dock, to ascertain the relative economic efficiencies of superheated steam used with different measures of expansion and without throttling; used with different boiler pressures, the same measure of expansion and without throttling; and used with throttling. Also, to ascertain the economic efficiency of saturated steam used with scarcely any expansion in a simple two cylinder engine formed by omitting the third or high pressure cylinder from the compound engine of the* CHER. *Likewise to ascertain the economic vaporization by the boiler.*

The data and results of the experiments made for the above purposes will be found in the following table, each column of which is appropriated to a single experiment and is lettered for facility of reference; the lines containing the quantities are grouped and numbered for the same reason. This table has the writer's own arrangement, but it contains every fact given in the original data.

Experiments A, B, C and D were made with superheated steam of the constant boiler pressure 27·53 pounds per square inch above the atmosphere, expanded 2·26, 3·21, 3·78 and 4·59 times, corresponding to cutting it off in the cylinders of a simple engine having the same waste spaces in clearance and steam passage, at 0·41, 0·27, 0·22 and 0·17 of the stroke of the piston from the commencement. The steam was used with a wide throttle and an average superheating of 14·1 degrees Fahrenheit on entering the valve chest.

Experiments E, F, G and H were duplicates of experiments A, B, C and D, respectively, except that they were made with steam of less boiler pressure and more superheated; the constant boiler pressure being 19·52 pounds per square inch above the atmosphere, and the superheating averaging 21·8 degrees Fahrenheit.

Experiments A to H, both inclusive, were made for the purpose of ascertaining the relative economic efficiencies of the different meas-

ures of expansion with which the steam was used; and the extent to which that economy was influenced for each measure of expansion by the difference of the boiler pressure in the two sets of experiments otherwise the same.

Experiments I, J, K and L were made to ascertain the relative economic efficiencies of superheated steam of different boiler pressures used with the same measure of expansion and without throttling. These pressures varied from 27·29 to 12·19 pounds per square inch above the atmosphere; the measure of expansion was 2·26 times; and the superheating varied from 11·5 to 30·3 degrees Fahrenheit, increasing as the boiler pressure decreased. Experiment I is experiment A, and experiment K is experiment E; experiments A and E being repeated in columns I and K for the purpose of completing the series in proper sequence.

Experiments M and N were made to ascertain the effect of throttling on the economic efficiency of the steam which was superheated, respectively, 19·9 and 16·3 degrees Fahrenheit, expended 2·26 times, and had the same boiler pressure of 27·87 pounds per square inch. In experiment M the throttle valve was 0·30 open, and in experiment N, 0·25.

Experiment O was made to ascertain the economic efficiency of saturated steam admitted to only the end cylinders and expanded therein 1·26 times, that being the greatest measure of expansion which could be obtained in these cylinders, as they had no expansion valves, and could cut off by the steam-lap alone on their main steam-valves. The middle cylinder was not in use, its connecting rod was disconnected from the crank-pin, its main steam-valve was removed from the valve-chest, and its steam-ports were securely closed, the boiler steam passed through its exhaust port to the valve-chests of the end cylinders. Although the boiler steam in experiment O was superheated 12·5 degrees Fahrenheit when entering the valve-chest of the middle cylinder, it had only the temperature due to its pressure as saturated steam in the reservoir, and it consequently entered the valve-chests of the cylinders without superheating.

The following are the quantities on the different numbered lines, and the manner in which they were obtained:

Line 1 contains the letters designating the experiments; and line 2 contains the date on which they were made.

Lines 3, 4 and 5 give the boiler power in use. They contain respectively the number of furnaces, and the square feet of grate surface and of water-heating surface in use. The steam superheating surface in use was 212·703 square feet in all the experiments.

Lines 6, 7 and 8 contain respectively the steam pressures in the boilers, in the steam-pipe near the middle cylinder just in advance of the throttle-valve, and in the reservoir between the middle and end cylinders, in pounds per square inch above the atmosphere.

Line 9 shows the proportion of the throttle-valve open. It was wide open in all the experiments except M and N.

Line 10 contains the fraction of the stroke of the piston of the middle cylinder completed when the steam was cut off. In experiment O, this point of cutting off is for the end cylinders, the middle cylinder being out of use.

Line 11 shows the number of times the steam was expanded during each experiment, and is inclusive of the effect of the waste spaces in the clearances of the pistons and in the steam passages.

Line 12 contains the number of double strokes made per minute by the pistons.

Line 13 contains the temperature of the steam in the steam-pipe near the middle cylinder due to its pressure as saturated steam, while line 14 contains its actual temperature by observation as indicated by a thermometer immersed in the pipe. The difference of the quantities on lines 13 and 14 is contained in line 15, which shows the superheating in degrees Fahrenheit possessed by the steam when entering the valve-chest of the middle cylinder.

Line 16 contains the temperature of the steam in the reservoir between the middle and end cylinders due to its pressure as saturated steam, and line 17 contains its actual temperature by observation, as indicated by a thermometer immersed in the reservoir. These quantities are exactly the same, and show, as expressed on line 18, that all the superheating had been lost in the middle cylinder, the steam entering the end cylinders being saturated.

Line 19 contains the *conjectured* temperature of the feed-water. In the original data of these experiments, this temperature is not noted; but it could have been only a few degrees, if any, different from what is given on line 19.

Line 20 contains the number of pounds of feed-water pumped into

the boilers per hour. It was measured in six of the vessel's tanks placed on the deck, three on each side, and connected by hose to the suction-valve chests of the two feed-pumps. The aggregate capacity of the six tanks was 700 cubic feet. The quantity of water to be used in any experiment was fixed in advance, and the time of using it was ascertained by observation. The experiments were always ended with the tanks just empty, so as to avoid any uncertainty in the measurement of fractional parts. The water for the tanks was obtained from the Arsenal through a hose, and had the temperature of the atmosphere.

Line 21 contains the number of pounds of water of condensation drawn per hour from the reservoir between the middle and end cylinders, and measured in a tank. This tabular quantity is necessarily much less than the real quantity, owing to evaporation in the tank. The water when drawn from the reservoir had the temperature of the steam pressure in the reservoir; but, when in the tank, being exposed to only the atmospheric pressure and temperature, a considerable quantity must have escaped in vapor. Besides this, a large portion of the water of condensation from the middle cylinder and reservoir must have been swept onward by the steam current into the end cylinders.

Line 22 contains the number of pounds of coal consumed per hour. This coal is a prepared fuel of very superior quality, employed exclusively for the trials of the machinery of French naval vessels. It is formed of the fine coal from the Anzin mines in the northeast of France, carefully washed, dried, and then mixed with just enough coal-tar to give coherence when forcibly compressed into the form of bricks. The fine coal itself, before washing, is of the best quality found on the continent of Europe; after washing, it has less that 4 per centum of ash, and it makes no clinker. Its cohesion is sufficient to prevent it from falling between the grate-bars in small pieces, and its economic vaporization and rate of combustion are about equal to that of the best Welsh steam coal. For these experiments, the coal was weighed into sacks, each sack containing the same number of pounds, so that the weight of coal consumed during an experiment was ascertained by merely counting the emptied sacks.

Lines 23 and 24 contain, respectively, the number of pounds of coal consumed per hour per square foot of grate surface and of

heating surface. These quantities are the quotients of the division of those on line 22 by the quantities on lines 4 and 5.

Lines 25 to 30, both inclusive, contain the pressures in pounds per square inch upon the steam-pistons as given by indicators attached to each end of each cylinder. A complete set of indicator diagrams was taken every half hour. On line 25 is the mean indicated pressure on the piston of the middle cylinder. The back pressure against that piston is not given in the original data of these experiments. On line 26 is the mean net pressure on the piston of the middle cylinder, obtained by subtracting 1·5 pounds per square inch from the mean indicated pressure upon it. On line 27 is the mean indicated pressure upon the pistons of the end cylinders; and line 28 contains the net pressure upon them, obtained by subtracting from the mean indicated pressure 1·5 pounds per square inch. Line 29 contains the mean back pressure against the pistons of the end cylinders; and line 30 contains the mean total pressure upon the pistons of the end cylinders, given by the addition of the quantities on lines 27 and 29.

Lines 31 to 38, both inclusive, contain the number of horse-power of 33,000 pounds raised one foot high per minute, developed by the engine. Lines 31 and 32 contain, respectively, the indicated and net horse-power developed by the middle cylinder alone, calculated from the area of the piston of that cylinder and the pressures on lines 25 and 26. Lines 33, 34 and 35 contain, respectively, the indicated, net and total horse-power developed by the end cylinders alone, calculated from the aggregate areas of their pistons and the pressures on lines 27, 29 and 30. Line 36 contains the aggregate indicated horse-power developed by all the cylinders, obtained by the addition of the quantities on lines 31 and 33. Line 37 contains the aggregate net horse-power developed by all the cylinders, obtained by the addition of the quantities on lines 32 and 34. Line 38 contains the total horse-power developed by all the cylinders, obtained by the addition of the quantities on lines 31 and 35.

Lines 39, 40 and 41 contain the number of pounds of coal consumed per hour per indicated, net and total horse-power developed by the engine. They are respectively the quotients of the division of the quantities on line 22 by those on lines 36, 37 and 38.

Lines 42, 43 and 44 contain the number of pounds of feed-water converted in steam consumed per hour per indicated, net and total

horse-power developed by the engine. They are respectively the quotients of the division of the quantities on line 20 by those on lines 36, 37 and 38.

Line 45 contains the number of Fahrenheit units of heat consumed per hour for total horse-power developed by the engine. These quantities are obtained by multiplying, respectively, those on line 44 by the number of Fahrenheit units of heat put into the feed-water by the combustion of the coal consumed. That number of Fahrenheit units will be the total heat in Fahrenheit units above zero of the boiler-steam, minus the 50 Fahrenheit units in the feed-water when pumped into the boilers, and plus the Fahrenheit units in the superheating obtained by multiplying the quantities on line 15 by 0·4805. The quantities on line 45 express relatively the true weights of fuel employed in the formation of the steam in the boiler.

Lines 46 and 47 contain what would have been the number of pounds of feed-water vaporized per hour by the coal on line 22, had its temperature, instead of being 50 degrees Fahrenheit, been, respectively, 100 and 212 degrees Fahrenheit, and had it been vaporized under the standard atmospheric pressure of 29·92 inches of mercury instead of the pressures on line 6.

The quantities on lines 48 and 49 are the quotients of the division of those on lines 46 and 47, by those on line 22, and give the comparable vaporizations of the feed-water per pound of coal under standard conditions.

Line 50 contains, in per centum of the weight of steam (line 20) evaporated per hour, the difference between that weight and the weight present in the middle cylinder at the moment when the cut off valve closed, calculated from the pressure of the steam at the point of cutting off as given by the indicator diagrams. The quantities on line 50 show the per centum of the steam entering the middle cylinder condensed in it when its piston had completed the 0·88 of the stroke.

Line 51 contains the quantities on line 50 increased or diminished in the ratio of 60 to the number of double strokes made by the pistons per minute on line 12. The purpose of the quantities on line 51 is to show the effect on the cylinder condensations of the number of double strokes made per minute by the pistons.

[To be continued.]

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IN CHERE RUCTION MOLL, BY
E OF THE PERHEATED STEAM
DIFFERENT ; AND USED WITH
WITH SCA E THIRD OR HIGH-

EXPANSION OF STEAM I

By Chief Engineer ISHE

TABLE CONTAINING THE DATA AND RESULTS OF THE EXPERIMENTS MADE AT THE MARINE ARSENAL IN CHERI SUB-ENGINEERS JOESSEL AND THIBAUDIER, OF THE FRENCH NAVY, ON THE COMPOUND ENGINE OF THE USED WITH DIFFERENT MEASURES OF EXPANSION AND WITHOUT THROTTLING; USED WITH DIFFEREN THROTTLING. ALSO, TO ASCERTAIN THE ECONOMIC EFFICIENCY OF SATURATED STEAM USED WITH SCA PRESSURE CYLINDER FROM THE COMPOUND ENGINE OF THE "CHER." LIKEWISE, TO ASCERTAIN THE E

NUMBER OF LINE.			EXPERIMENTS MADE TO ASCI HEATED STEAM USED WI THROTTLING. Maximum Boiler Press		
			A	B	C
1		Designation of experiment,			
2		Date of experiment,	February 8.	February 5.	February
3		Number of furnaces in use,	6	6	6
4		Square feet of grate surface in use,	87·514	87·514	87·51
5		Square feet of water-heating surface in use,	2249·525	2249·525	2249·52
6	ENGINE.	Steam pressure in boilers, in pounds per square inch above the atmosphere,	27·29	27·67	27·29
7		Steam pressure in steam-pipe near the cylinders, in pounds per square inch above the atmosphere,	26·22	26·71	26·36
8		Steam pressure in reservoir between middle and end cylinders, in pounds per square inch above the atmosphere.	19·35	14·13	12·19
9		Proportion of the throttle-valve open,	1·00	1·00	1·0
10		Fraction of the stroke of the piston of the middle cylinder completed when the steam was cut off,	0·88	0·60	0·50
11		Number of times the steam was expanded,	2·26	3·21	3·78
12		Number of double strokes of pistons made per minute,	66·34	61·37	58·14
13	TEMPERATURES.	Temperature, in degrees Fahrenheit, of the steam in the steam-pipe near the cylinders, normal to its pressure as saturated steam, according to Regnault,	268·5	269·2	268·7
14		Temperature, in degrees Fahrenheit, of the steam in the steam-pipe near the cylinders, by observation,	280·0	285·4	279·5
15		Number of degrees Fahrenheit that the steam was superheated on entering the middle cylinder,	11·5	16·2	10·8
16		Temperature, in degrees Fahrenheit, of the steam in the reservoir normal to its pressure as saturated steam,	257·5	248·0	244·1
17		Temperature, in degrees Fahrenheit, of the steam in the reservoir, by observation,	257·5	248·0	244·1
18		Number of degrees Fahrenheit that the steam was superheated on entering the reservoir,	0·0	0·0	0·0
19		Probable temperature of the feed-water, in degrees Fahrenheit,	50·0	50·0	50·0
20	WATER.	Number of pounds of feed-water pumped into the boilers per hour,	11574·885	8181·790	7083·12
21		Number of pounds of water of condensation drawn from the reservoir per hour,	37·717	35·276	30·86
22	RATE OF COMBUSTION.	Number of pounds of coal (briquettes d'Anzin) consumed per hour,	1355·915	1009·771	881·89
23		Number of pounds of coal consumed per hour per square foot of grate surface,	15·494	11·538	10·07
24		Number of pounds of coal consumed per hour per square foot of heating surface,	0·603	0·449	0·39
25	STEAM PRESSURES IN CYLINDERS, Per Indicator.	Mean indicated pressure on the piston of the middle cylinder, in pounds per square inch,	18·926	19·197	18·57
26		Mean net pressure on the piston of the middle cylinder, in pounds per square inch,	17·426	17·697	17·07
27		Mean indicated pressure on the pistons of the end cylinders, in pounds per square inch,	16·080	11·186	9·60
28		Mean net pressure on the pistons of the end cylinders, in pounds per square inch,	14·580	9·686	8·10
29		Mean back pressure against the pistons of the end cylinders, in pounds per square inch,	1·273	1·070	1 47
30		Mean total pressure on the pistons of the end cylinders, in pounds per square inch,	17·353	12·256	11·08
31	HORSES-POWER.	Indicated horses-power developed by the middle cylinder,	182·312	171·069	156 83
32		Net horses-power developed by the middle cylinder,	167·863	157·702	144·17
33		Indicated horses-power developed by the end cylinders,	309·793	199·362	162·19
34		Net horses-power developed by the end cylinders,	280·895	172·628	136·86
35		Total horses-power developed by the end cylinders,	334·319	218·432	187·07
36		Aggregate indicated horses-power developed by all the cylinders,	492·105	370·431	319·03
37		Aggregate net horses-power developed by all the cylinders,	448·758	330·330	281·04
38		Aggregate total horses-power developed by all the cylinders,	516·631	389·401	343 91
39	ECONOMIC RESULTS.	Pounds of coal consumed per hour per indicated horse-power,	2·755	2·726	2 76
40		Pounds of coal consumed per hour per net horse-power,	3 021	3·057	3·13
41		Pounds of coal consumed per hour per total horse-power,	2·625	2·593	2·56
42		Pounds of feed-water consumed per hour per indicated horse-power,	23·521	22·088	22·04
43		Pounds of feed-water consumed per hour per net horse-power,	25·793	24·768	25·02
44		Pounds of feed-water consumed per hour per total horse-power,	22·406	21·011	20·45
45		Fahrenheit units of heat consumed per hour per total horse-power,	25942·115	24251·243	23548·36
46	VAPORIZATION.	Pounds of feed-water that would have been vaporized per hour, had it been supplied at the temperature of 100 degrees Fahrenheit, and vaporized under the standard atmospheric pressure of 29·92 inches of mercury.	12302·377	8697·238	7475·16
47		Pounds of feed-water that would have been vaporized per hour, had it been supplied at the temperature of 212 degrees Fahrenheit, and vaporized under the standard atmospheric pressure of 29·92 inches of mercury.	13739·797	9713·429	8348·56
48		Pounds of water vaporized from 100 degrees Fahrenheit by one pound of coal,	9·073	8·613	8·47
49		Pounds of water vaporized from 212 degrees Fahrenheit by one pound of coal,	10·133	9·618	9·46
50	CONDENSATION.	Difference, in per centum of the weight of steam evaporated per hour in the boilers, between that weight and the weight of steam per indicator in the middle cylinder at the moment when its cut-off valve closed,	8·980	15·990	21·29
51		The quantities on line 50 increased or diminished in the ratio of 60 to the number of double strokes made by the pistons per minute,	9·922	15·958	20·63

AM IN THE STEAM-ENGINE.

EER ISHERWOOD, U. S. NAVY.

IN CHERBOURG, DURING FEBRUARY, 1866, UNDER THE SUPERVISION OF DIRECTOR OF NAVAL CONSTRUCTION MOLL, BY
OF THE WAR STEAMER "CHER," TO ASCERTAIN THE RELATIVE ECONOMIC EFFICIENCIES OF SUPERHEATED STEAM
IFFERENT BOILER PRESSURES, THE SAME MEASURE OF EXPANSION AND WITHOUT THROTTLING: AND USED WITH
WITH SCARCELY ANY EXPANSION IN A SIMPLE TWO-CYLINDER ENGINE, FORMED BY OMITTING THE THIRD OR HIGH-
IN THE ECONOMIC VAPORIZATION BY THE BOILER.

DE TO ASCERTAIN THE RELATIVE ECONOMIC EFFICIENCIES OF SUPER-M USED WITH DIFFERENT MEASURES OF EXPANSION AND WITHOUT						EXPERIMENTS MADE TO ASCERTAIN THE RELATIVE ECONOMIC EFFICIENCIES OF SUPERHEATED STEAM OF DIFFERENT BOILER PRESSURES USED WITH THE SAME MEASURE OF EXPANSION AND WITHOUT THROTTLING.				EXPERIMENTS MADE TO ASCERTAIN THE INFLUENCE OF THROTTLING ON THE ECONOMIC EFFICIENCY OF SUPERHEATED STEAM.		Working as a simple engine with scarcely any expansion of the steam, which was saturated and admitted to only the two end cylinders by passing it through the middle cylinder whose exhaust ports were closed tightly, and the connecting rod disconnected.
Boiler Pressure.		Medium Boiler Pressure.										
5.	C February 6.	D February 7.	E February 22.	F February 21.	C February 20.	H February 23.	I February 8.	J February 9.	K February 22.	L February 23.	M February 10.	N February 16.	O February 19.
	6·	6·	6·	6·	4·	4·	6·	6·	6·	4·	6·	6·	6·
	87·514	87·514	87·514	87·514	58·342	58·342	87·514	87·514	87·514	58·342	87·514	87·514	87·514
	2249·525	2249·525	2249·525	2249·525	1499·684	1499·684	2249·525	2249·525	2249·525	1499·684	2249·525	2249·525	2249·525
	27·29	27·87	19·55	19·45	19·35	19·72	27·29	21·09	19·55	12·19	27·87	27·87	18·54
	26·36	26·96	18·62	18·47	18·38	19·06	26·22	20·03	18·62	11·61	26·90	26·90	17·80
	12·19	10·45	15·09	10·45	9·48	8·71	19·35	16·26	15·09	11·76	14·71	12·77	15·00
	1·0	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	0·30	0·25	1·00
	0·50	0·40	0·88	0·60	0·50	0·40	0·88	0·88	0·88	0·88	0·88	0·88	0·78
	3·78	4·59	2·26	3·21	3·78	4·59	2·26	2·26	2·26	2·26	2·26	2·26	1·26
	58·14	54·57	58·78	53·70	51·10	48·14	66·34	61·25	58·78	51·25	59·68	53·68	66·27
	268·7	269·6	256·3	256·0	255·9	257·1	268·5	258·7	256·3	242·9	269·5	269·5	254·9
	279·5	287·6	278·4	276·8	278·6	278·6	280·0	280·4	278·4	273·2	289·4	285·8	267·4
	10·8	18·0	22·1	20·8	22·7	21·5	11·5	21·7	22·1	30·3	19·9	16·3	12·5
	244·1	240·4	249·8	240·4	238·2	236·4	257·5	252·0	249·8	243·2	249·1	245·8	249·7
	244·1	240·4	249·8	240·4	238·2	236·4	257·5	252·0	249·8	243·2	249·1	245·8	249·7
	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	50·0	50·0	50·0	50·0	50·0	50·0	50·0	50·0	50·0	50·0	50·0	50·0	50·0
0	7033·121	6052·011	8477·225	5831·537	5208·186	4488·851	11574·885	9414·240	8477·225	5926·341	8201·683	6991·230	16548·778
6	30·866	35·276	17·638	15·433	15·433	15·433	37·481	26·457	17·638	8·819	22·047	13·890	2·205
1	881·896	787·092	1047·271	780·478	705 517	621·737	1355·915	1159·693	1047·271	734·178	1144·260	932·681	2017·337
8	10·077	8·994	11·967	8·918	12·093	10·657	15·494	13·251	11·967	12·584	13·075	10·655	23·052
9	0·392	0·350	0·465	0·347	0·470	0·414	0·603	0·515	0·465	0·489	0·509	0·415	0·897
7	18·578	18·739	14·872	16·250	15·366	14·034	18·926	15·803	14·872	11·091	15·215	13·870	.....
7	17·078	17·239	13·372	14·730	13·866	12·534	17·426	14·303	13·372	9·591	13·715	12·370	.....
3	9·606	7·660	12·337	8·182	7·354	6·508	16·080	13·277	12·337	9·537	12·018	10·208	25·545
6	8·106	6·160	10·837	6·682	5·854	5·008	14·580	11·777	10·837	8·037	10·518	8·708	24·045
9	1 474	1·678	1·354	1·451	1·432	1·892	1·278	1·312	1·354	1·480	1·379	1·217	3·452
6	11·080	9·338	13·691	9·633	8·786	8·400	17·353	14·589	13·691	11·017	13·397	11·425	28·997
9	156 839	148·484	126·934	126·553	114·015	98·100	182·312	140·548	126·934	82·547	131·850	108·111	.....
2	144·176	136·599	114·132	114·857	102·885	87·617	167·863	127·208	114·132	71·383	118·852	96·419	.....
2	162·192	121·393	210·596	127·598	109·133	90·988	309·793	236·166	210·596	141·963	208 292	159·134	491·625
8	136·865	97·621	184·761	104·206	86·873	70·053	280·895	209·484	184·761	119·635	182·294	135·750	462·756
2	187·079	147·985	233·709	150·226	130·384	117·435	334·319	259·503	233·709	163·993	232·192	178·106	558·060
1	319·031	269·877	337·530	254·151	223·148	189·088	492·105	376·714	337·530	224·510	340·142	267·245	491·625
0	281·041	234·220	298·893	219·063	189·758	157·670	448·758	336·692	298·893	191·018	301·146	232·169	462·756
1	343 918	296·469	360·643	277·824	244·399	215·585	516·631	400·051	360·643	246·540	364·042	286·217	558·060
6	2 764	2·917	3·103	3·071	3·162	3·288	2·755	3·078	3·103	3·270	3·364	3·490	4·103
7	3·138	3·360	3·460	3·563	3·718	3·943	3·021	3·445	3·460	3·843	3·800	4·017	4·359
3	2·564	2·655	2·904	2·809	2·887	2·885	2·625	2·899	2·904	2·978	3·143	3·259	3·615
8	22·045	22·425	25·115	22·945	23·317	23·739	23·521	24·990	25·115	26·397	24·112	26·160	33·661
8	25·025	25·839	28·362	26·620	27·420	28·470	25·793	27·961	28·362	31·025	24·235	30·113	35·761
1	20·450	20·414	23·506	20·990	21·290	20·826	22·406	23·532	23·506	24·038	22·529	24·426	29·654
3	23548·367	23582·641	27107·802	24201·907	24553·772	24012·810	25942·115	27151·618	27107·802	28092·489	26096·497	28197·427	34032·553
8	7475·160	6433·789	8980·867	6177·677	5511·783	4755·872	12302·877	9980·360	8980·867	6255·134	8719·776	7432·271	17523·676
9	8348·563	7185·517	10030·198	6899·481	6155·783	5311·551	13739·797	11146·472	10030·198	6985·988	9738·600	8300·647	19571·153
3	8·476	8·174	8 575	7·915	7·812	7·649	9·073	8·606	8·575	8·520	7·620	7·967	8·687
8	9·467	9·129	9·577	8·840	8·725	8·543	10·133	9·612	9·577	9·515	8·511	8·898	9·701
0	21·290	27·210	9·697	18·703	24·025	31·425	8·980	9·725	9·697	11·691	.....	.....	.....
8	20·630	24·733	9·493	16·736	20·441	25·198	9·922	9·879	9·493	9·983	.....	.....	.....

MEMOIRS ON THE LIQUEFACTION OF OXYGEN, THE LIQUEFACTION AND SOLIDIFICATION OF HYDROGEN, AND ON THE THEORIES OF THE CHANGES IN CONDITION OF BODIES.

By R. PICTET.

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[Continued from Vol. lxxv, page 329.]

II.—DESCRIPTION OF THE APPARATUS.

In the preceding chapter we have established the apparent antagonism existing between vapors and permanent gases; an antagonism resting principally on the anomalies of the law of Mariotte and on the impossibility of liquefying these gases, notwithstanding fabulous pressures.

Theory has led us to recognize the necessity of modifying the condition of the permanent gases, in two manners: by submitting them to increasing pressures and by lowering their temperature as much as possible.

We will now describe the mechanical devices chosen to attain this double purpose:

Before adopting any plan, notwithstanding a well-defined purpose, all the requisite conditions must be considered, to ensure a continuous operation, to eliminate error and the unforseen, which too often thwarts our purpose, veiling the distinctness of the phenomena to be observed, introducing disturbing elements which prevent accuracy of observation.

To succeed in liquefying the permanent gases, we find that the mechanical appliances must fulfil five essential conditions. They are all based on known facts relating to the liquefaction of other vapors. They are:

1. To operate on a gas absolutely pure, with no trace of a foreign gas.

2. To be able to compress this gas methodically; to obtain considerable pressures; and to be able to measure these pressures accurately.

3. To have the lowest possible temperatures available; to be able to maintain them indefinitely, at the same time abstracting heat at these low temperatures.

4. To have a large condensing surface, maintained at these low temperatures.

5. To be able to make use of the expansion of the gases, from their great pressure to the atmospheric pressure; which expansion, when added to the preceding aids, induces liquefaction.

These five conditions are equally important. If the gas were impure, liquefaction might be due to the foreign gas. The laws of pressure, when applied to temperatures, are disturbed by the presence of a foreign gas, in the one under investigation. It is, therefore, absolutely necessary to operate on a chemically-pure gas. 800 atmospheres have seemed, to us, as a sufficiently high limit for a first series of experiments. We have used a metallic manometer, manufactured expressly for this purpose, by M. Bourdon, and graduated, with the greatest care, by means of hydraulic pressures measured by a balance. Without being absolutely correct, this apparatus is sufficiently accurate to record a pressure to within 1 or 2 atmospheres; which suffices.

The manner of producing low temperatures will be the subject of the following description: It is the most expensive and most delicate of the mechanical part. A large condensing surface is necessary for the compressed gases, as the majority of the experiments previously undertaken with this object have miscarried for want of proper precaution in this respect.

A given surface will only condense a certain quantity of vapor. If this surface is small, if the sides are bad conductors of heat, the phenomenon of condensation will be greatly retarded. On this account, we do not wish to use thick glass tubes, and will give a large surface to the metal tube destined to condense the gas. Finally, in case the pressure obtained, joined to the influence of the temperature, should not suffice to bring liquefaction to a static condition, it can be accomplished by the expansion of the gas.

Let us imagine the gas compressed to a pressure of 500 atmospheres, and kept at — 100°; under these conditions it would still be gaseous. If we expand it from the pressure of 500 atmospheres to the atmospheric pressure, this expansion will perform considerable

work. This work will be given out at the expense of the temperature of the gas, but this reduction of the temperature might be such that the gas would lose every trace of heat, and that a part of it would pass through absolute zero; the point where the calorific vibration is naught. Evidently, in this case, the cohesion, "if it is a universal force," would produce the liquid, and perhaps the solid, condition of the body under investigation.

In order to base this deduction on more accurate figures, we would remark that one kilogramme of oxygen would generate, as work of expansion, 49·664 kilogrammetres; whereas the total heat represented by a kilogramme of oxygen, from — 100° to absolute zero, is only 37·9 calorics (French), which, transformed into work, only gives 16·334 kilogrammetres.

This shows that a complete expansion would not be possible; but a gas has, as a distinctive characteristic, an unlimited expansion, on account of which characteristic, lost during the operation, a part of the gas will condense and pass over into the solid or liquid condition. If this change did not occur, a part of the gas would become an inert dust, and then cohesion would not be a general law of nature.

This is, therefore, an absolute and final criterion. The expansion of compressed gases will furnish an unimpeachable proof.

Those are the principal considerations which have guided us in the mechanical arrangement we have adopted to liquefy the permanent gases.

We will now briefly describe the apparatus themselves. They may be divided into three distinct parts:

1. A circulation of sulphurous acid, producing a first fall in temperature.

2. A circulation of carbonic acid or of protoxide of nitrogen, which induces a second fall of temperature.

3. The generation of oxygen in a closed vessel, placed in contact with the solidified carbonic acid, in a long, fine tube, completely immersed in this carbonic acid.

Plate 1 shows plan and elevation of the arrangement.

These apparatus were placed in a building belonging to the Society of Geneva, for the manufacture of philosophical instruments.

M. Th. Turrettini, the director of this society, kindly authorized me to make use of his rooms and his steam engine, to facilitate my researches and experiments.

I avail myself of this opportunity to acknowledge my deep obligations to him as well as to the society he represents. All the instruments used were manufactured in this establishment, and it is solely due to their perfection, that accurate results were obtained without any accident whatsoever.

Fig. 1 represents an elevation of the whole apparatus. It shows a longitudinal section of two large drums, *U* and *V*.

In the upper one, *U*, is a large copper tube, *R*, of 12 centimetres diameter and 1 m. 10 in. in length. This tube traverses the drum from end to end, slightly inclined. The difference in level between the two extremities is 12 centimetres.

The liquid sulphurous acid is introduced into this tube through pipe *Z*, which enters on the upper side of the lower end of this cylinder. When the sulphurous acid has accumulated in this recipient so that the level of the liquid reaches the orifice of the tube *Z*, the surface of this liquid is at a maximum as it extends over the greatest cross-section from end to end.

A cock *r*, of 20 millimetres diameter, is placed on the upper end of the large tube containing sulphurous acid. This cock is opposite the tube for the admission of the liquid, placed at the other end. A long tube, 25 m. m. in diameter, connects this cock *r* with the suction of the first pump *P*.

If this pump be driven by means of any transmission of power, it will produce a partial vacuum over the sulphurous acid contained in tube *R*. Volatilization of the sulphurous acid will be immediately induced, and the temperature of this liquid will rapidly fall. The more perfect the vacuum, the lower it will drop.

In physical laboratories, air-pumps are generally used to create a vacuum; these delicate instruments would not suit this class of experiments which demand a continuous operation extending over many hours, and the abstraction of an enormous quantity of heat. On the other hand, common pumps do not render very good performance, and will not readily give us a perfect vacuum. I have surmounted the difficulty by coupling two pumps, similar to those used by us in our ice machines, and arranging them so that the suction of the second pump *P'* (Fig. 2), corresponds to the compression of the first *P*.

Owing to this arrangement, the clearance of the first pump, the piston leakage, small mechanical imperfections inherent to large industrial apparatus are completely neutralized and the suction becomes as energetic as that of the best air pumps. A few figures will suffice to show the remarkable efficiency of this arrangement.

I have obtained a vacuum of ½ millimetre in a flask containing liquid sulphurous acid, with an excellent air pump, having cylinders of 750 cubic centimetres capacity. The weight of the flask and acid was 320 grammes. The flask was wrapped in rags and cotton waste to prevent radiation or conduction of heat.

After having pumped without intermission for more than three-quarters of an hour, there being four of us to take turns, the indicated temperature was only — 54° ; twenty minutes later it was only — 55°, and we were unable to lower it.

With the two pumps coupled as described, the temperature of tube *R*, as indicated by the same alcohol thermometer was — 30° after four minutes' operation; —45° after ten minutes, and finally descends gradually to — 73°, the lowest limit we could reach.

The alcohol thermometer fits a small copper sleeve, the mouth of which opens into the side of the large reservoir *R*. The other extremity is closed, and the whole tube immersed in the liquid sulphurous acid. A little absolute alcohol is poured into this sleeve so as to establish contact between the walls of the tube and the thermometer.

The pumps *P* and *P'* are of cast iron, constructed on Prof. Daniel Colladon's plan, as applied to air compressors. The piston is hollow and is furnished with a circulation of water, which enables the packing to resist for a long time the injurious effects of the elevation of temperature; which cannot be counteracted without this expedient. The packing is composed of two parts, separated by a metallic ring. This ring takes the place of a chamber and serves to prevent the entrance of air. It acts in this manner: the second pump *P'* compresses the sulphurous acid to 1 or 2 atmospheres in a condenser C. This condenser is of copper, and has the shape of a tubular boiler. A current of water traverses the tubes of this condenser, and takes up the heat developed by the change of condition.

As the pressure produced by the second pump, when compressing, exceeds the atmospheric pressure, it is only necessary to join the metallic rings in the piston packing of the two pumps *P* and *P'* by a

pipe, to the connection of pump P', with the condenser C; there is then no danger of an entrance of air into the apparatus. Should such an accident occur, it would immediately paralyze the action of the pumps, as the pressure of the gases in the condenser C would be constantly increasing and would soon exceed the assumed limits.

This precaution, of a purely practical nature, is indispensable to insure a performance of any duration.

The volume of pump P being three litres per stroke, explains the rapidity with which the temperature descends in tube R, as soon as the operation begins.

The valves of pumps P and P' have been made with very particular care. They are of steel, and the carefully ground seats of the clacks are of brass. The springs on the suction valves are very weak, but just strong enough to close the valve. The speed of the pumps varies between 80 and 100 revolutions per minute.

The sulphurous acid which is evaporated in tube R, owing to the large surface of the liquid exposed, passes through cock r into the first pump, thence into the second, and finally into the condenser. There the vapors condense, resume their liquid state and find their way to the lower part of the condenser. Here I have placed the opening for tube Z, which connects the condenser with tube R. A regulating screw valve q, enables us to give the necessary section of opening, so that the weight of liquid which flows out under the difference of pressure between the condenser and the tube R, may be exactly equal to that of the vapors exhausted during the same time.

As this weight is extremely small, representing but a few grammes a minute, it will suffice to barely open the valve q, giving the stem one-tenth of a turn at the most. In this manner the level of the liquid in tube R, will remain constant.

The cycle of the sulphurous acid is complete and the fall of temperature obtained in the large tube R will be permantly maintained by the mechanical work of the pumps P and P'.

This first circulation of sulphurous acid, is but an "expedient" to obtain carbonic acid or protoxide of nitrogen in a liquid state, in sufficient quantities. Should it be desirable to condense carbonic acid or protoxide of nitrogen by ordinary pumps, it would be necessary to subject these gases to pressures exceeding 30 to 40 atmospheres, even when using very cold water for the condensation.

These pressures cannot be obtained on a large scale; they can only be realized by means of special pumps, whose sale is very limited and which cannot stand continuous work.

If on the contrary, carbonic acid be compressed at a temperature of — 65°, the pressure falls to 4 or 6 atmospheres, a pressure very readily obtainable by means of pumps similar to *P* and *P'*. With this object I have placed in the centre of tube *R* a second tube, of a lesser diameter, having a length of 1·15 m. and 6 centimetres in diameter. This tube, marked *S* is consequently immersed in the sulphurous acid which totally envelops it, and it shares the low temperature of — 65°. Tube *S* acts as a condenser for the carbonic acid which is compressed in it by the action of two pumps *O* and *O'*, resembling pumps *P* and *P'* in every respect and similarly arranged.

The carbonic acid is prepared with great care in two large glass jars filled with pieces of Carrara marble on which chlorhydric acid, added from time to time, is allowed to act. The disengaged gas is washed, then dried by a large apparatus full of chloride of calcium. It is then stored in an oil gasometer (*G*, Figs. 1 and 2), having a capacity of 1 cubic metre. A pipe, *C*, connects the gasometer with a three-way cock, *K* (Fig. 2).

On commencing the operation, this cock *K* is turned that the gasometer *G* is connected with the suction of pump *O* by means of pipes *C* and *C'*. The pumps *O* and *O'* are not started until the lower temperature has already been obtained in tube *R* by the action of pumps *P* and *P'*.

The condensation of the carbonic acid in tube *S* takes place immediately, under a pressure indicated by the manometer, *m*. It varies according to the quantity of gas admitted to the pumps *O* and *O'*, but generally remains between 4 and 7 atmospheres. The temperature of the sulphurous acid always rises a little as soon as pumps *O* and *O'* have been set in motion.

This result is natural, as the carbonic acid which liquefies gives off all its latent heat to the sulphurous acid; the temperature consequently rises to — 50°. As soon as the condensation of the carbonic acid is retarded, this temperature re-descends immediately, oscillating constantly between — 50° and — 65°. All the gas contained in the gasometer will be drawn through the pumps, *O* and *O'*, and will be compressed in tube *S*, where it liquefies readily. More than 2 kilogrammes may thus be obtained in a quarter of an hour. The car-

bonic acid once obtained, it is only necessary to use it for the condensation of the oxygen.

The special apparatus arranged for this purpose are placed in the long drum, *V*, which is just below the first one. This drum, similar to drum *V*, contains two copper tubes; their dimensions, however, are notably different.

A first and exterior tube is exactly 3·70 m. long, and 35 mm. in exterior diam. It is slightly inclined towards the ground, but in the opposite direction to tubes *R* and *S*. It is marked *D* in Figs. 1 and 2. This tube connects with the reservoir of liquid carbonic acid by the pipe, *t*. A regulating screw-valve, *p*, exactly similar to the regulating valve of the sulphurous acid, allows an opening or closing of the connection, as well as a regulating of the size of the orifice. I have placed the delivery of the liquid carbonic acid about the centre of the long tube, *D*, for a reason which I shall give later.

A second flange, *f* (Fig. 2), placed at the upper part of *D*, allows us to insert a pipe, *C'*, which leads from *f*, and establishes a connection between the top of tube *D* and the three-way cock, *K*. This arrangement given, let us see how the second circulation takes place. We commence by drawing off the gas from the gasometer, previously filled. As soon as all the gas has been liquefied in the condenser, *S*, the regulating valve, *p*, is opened; the carbonic acid enters tube *t*, and immediately lowers the temperature of tube *D*. The first drops which enter the long tube, *D*, meeting a metallic surface of the usual surrounding temperature, evaporate rapidly, and the vapors generated return to the condenser, *S*, to be re-condensed.

As soon as an equilibrium of pressure is re-established, a second quantity of the liquid descends into the tube, and produces a still greater lowering of the temperature of the sides of tube *D*. The carbonic acid thus gradually descends into the lower tube, *D*; accumulating, first, in its lowest part, the level gradually rises to the upper part, at flange *f*.

During this operation the manometer, *m*, which indicates the pressure in condenser *S*, informs us of what is occurring. Each time a certain quantity of liquid carbonic acid descends into tube *D*, still warm when compared with the very low temperature of the carbonic acid, a sudden rise of 2 or 3 atmospheres is visible on the manometer, *m*. This increase disappears rapidly, as it is caused by a reflux of the gaseous acid, which re-condenses and re-descends into tube *D*.

The manometer, *m*, having come to a standstill, indicating that the whole tube has acquired a temperature corresponding to that of the sulphurous acid in *R*, *i. e.*, about — 60° to — 65°, the three-way cock, *K*, is turned, so as to disconnect the gasometer and to connect the suction of pump *O* with the upper part of tube *D*, through pipes *C* and *C''*.

Great care should be exercised with this experiment, for should this cock be opened suddenly, the liquid contained in *D* would start into spontaneous ebullition, notwithstanding the low temperature, and a considerable quantity of this liquid would find its way into the piping and pumps. There the high temperature would develop such quantities of vapor that the surface of condenser *S* would be altogether insufficient to re-condense it. The pressure would reach 30 or 40 atmospheres in a few seconds, and an accident would certainly occur.

This connection should, therefore, be opened but gradually, so as to diminish the pressure of the carbonic acid slowly and uniformly. The regulating valve, *p*, should also be left open for a short while, so that we may be assured that all the liquid carbonic acid has descended into tube *D*. The difference in pressure caused by the action of the pumps will certainly accomplish it.

Close the regulating cock as soon as a thick hoar-frost whitens the piping *C'' C;* this is a certain sign that the whole of tube *D* is full of liquid. At this moment a new and considerable reduction of temperature takes place. A vacuum is formed over the liquid carbonic acid, and the cold becomes so intense that this acid solidifies.

MEASUREMENT OF THE TEMPERATURES.

It is impossible to use alcohol thermometers to estimate temperatures so low. The contraction and dilation of this liquid no longer gives any reliable guarantee. For the measurement of these temperatures I have used the following formula, which I have derived directly from the mechanical theory of heat, applied to changes of condition:

$$l\left(\frac{P'}{P}\right) = \frac{[\lambda' + (c-k)(t'-t)]\,431 \times 1{\cdot}293\,\delta \times 274\,(t'-t)}{10333\,[(274+t')^2 - (274+t')(t'-t)]}.$$

In this equation, $l\left(\frac{P'}{P}\right)$ is the Naperian logarithm of the quotient of the tensions at a point of saturation, at the temperatures t' and t.

t' is a fixed temperature, taken as a starting point; 0° or 100°, if possible, or an intermediate temperature given by a standard thermometer.

t is the temperature to be determined.

P is the tension recorded by the manometer when a vacuum is established, and corresponds to a temperature t.

P' is the tension of the vapor at a temperature t', and is given in M. Regnault's tables.

λ' is the latent heat of volatilization at the temperature t'.

c is the specific heat of the liquid, a mean between t' and t.

k is the specific heat of the vapor at a constant pressure.

δ is the density of the vapor compared with that of air; a density varying slightly with the pressure P, and which we can ascertain exactly by means of the law of co-volumes, given by M. Regnault.

If we give t successive values, and each smaller by 10 degrees than the preceding value, the curve of maximum tensions corresponding to the temperatures may be drawn; this curve furnishes a means for very exact and rapid observations of the temperatures.

This is not the place to derive this formula, nor the equations on which it is based. We would merely remark, that as applied to the vapors of water, of sulphurous acid, etc., it agrees to within a millimetre with the tables of M. Regnault, between the limits $t' = 200°$, and $t = 0°$, which limits correspond to the greatest differences, and have been determined with the greatest care.

We have just explained how the second circulation, of carbonic acid, or of protoxide of nitrogen is caused. Either gas may be used. This second circulation produces a fall of temperature, which reaches $-120°$, and even $-140°$, when the vacuum is a perfect one.

We will now take up oxygen and the appliances which enable us to utilize this intense cold, and to obtain a considerable pressure.

I have placed a second tube in the interior of tube D, smaller as regards diameter, but about 50 centimetres longer. This small tube is very thick, its interior diameter is exactly 4 mm., and its exterior diameter is 15 mm.; the length of this tube A (Figs. 1 and 2) is 4·16 m. This tube transverses the two heads of tube D, protrudes a few centimetres from the lower end, and about 50 cm. from the upper end. It is to serve as a reservoir for the compressed oxygen. A thread is cut on the lower part of this copper pipe, about 6 in. long; a steel sleeve, which has previously been tinned, is screwed on

to it. On heating it a perfectly soldered joint is obtained. The steel sleeve is pierced in two places, at one a large metallic manometer, m' (Figs. 1 and 2), is attached, graduated up to 800 atmospheres.

The diameter of this manometer is sufficiently large to readily show the tenth of each division, corresponding to 10 atmospheres. The pressure can consequently be estimated to within one atmosphere.

The manometer connects with the central part of tube A, through a hole in the side of this tube, opposite the opening in the sleeve. The joint of the sleeve and manometer is made perfectly tight by means of a copper washer interposed between the two faced surfaces of the joint. This washer is slightly dished on both sides and makes so perfect a joint that no leakage need be feared.

The second orifice of the steel sleeve is for the passage of the liquid oxygen, and is placed below the manometer m'. It is very small, only 3 mm. in diameter. A small bushing, perforated by a hole of 1 mm. diameter, is screwed into this opening. Through its extremity the compressed gas and liquid will escape as soon as the steel screw v, which closes the extreme end of tube A, has been unscrewed.

The steel sleeve envelops the end of tube A completely. If a screw with a tapering point be screwed into the sleeve opposite the end of, and parallel to, the axis of the mouth of this tube, it will entirely close the opening of tube A as soon as the point is forced into the same. There is no danger of spreading the copper by a strong pressure as it is securely held by the sleeve. This arrangement gives the most satisfactory results.

The upper part of tube A is bent down towards the earth and connects with a large wrought iron flask B (Figs. 1 and 2). This flask was forged with the greatest care, so as to insure an exceptional quality and homogeneity of metal. In the interior is a cavity of exactly 1659 cubic centimetres capacity, The exterior dimensions are, 28 centimetres in length and 17 centimetres in diameter. The sides have an average thickness of 35 millimetres. A determination of its strength shows that such a flask can resist a pressure of more than 1500 atmospheres. The connection of tube A with flask B is made by means of a double joint similar to that at the manometer m'. A steel screw plug is screwed on to the end of tube A, and into the opening of the flask. A copper washer makes the joint and prevents any leakage of gas.

Before making the joint a known weight of chlorate of potassa, mixed with chloride of potassium, is introduced into the flask, which is then screwed on to the end of tube *A*. A crown jet of gas, similar to that used in the Perrot furnace, is employed.

Carefully regulating the flame, the temperature of the flask is gradually raised to the 485 to 500 degrees necessary for the perfect liberation of the oxygen. The mamometer *m'* enables us to follow the course of the operation. This arrangement allows us to dispense with the pumps for the compression of the gas; the chemical reaction being the sole source of the pressure.

The surface of tube *A* is relatively large, as 3 m. 62 c. of its length is imbedded in the solid carbonic acid.

Pipe *t* was connected with tube *D*, near the middle, so as not to run the risk of suddenly increasing the temperature of the liquefied oxygen, which will collect in the lower part of tube *A*.

The liquid carbonic acid does not enter tube *D* at its lowest temperature; a certain lapse of time is necessary to complete the reduction of temperature; during this time the condensed gas is necessarily under the influence of this calorific oscillation. The lower end, between pipe *t* and the manometer *m'*, however, solves the difficulty, as the crystallized carbonic acid therein maintains a constant minimum temperature.

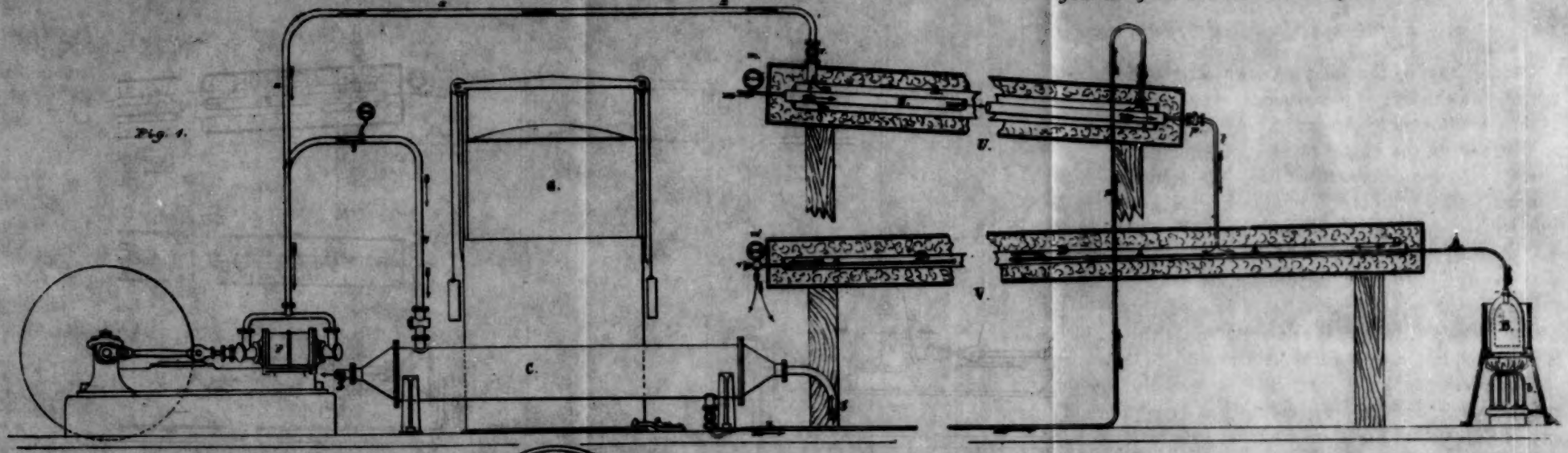
These are the general arrangements I have adopted to attempt the liquefaction of oxygen experimentally.

The preceding description having been necessarily long and interspersed with secondary details, I will recapitulate briefly, confining myself to the essential conditions, and will present them in an inverse order to that just followed.

Our object is to liquefy oxygen gas by means of low temperature and strong pressure.

In order to generate oxygen, we use a hollow iron flask, in which chlorate of potassa is placed, and which is gradually heated. The oxygen compresses itself in the enclosed space, by the energy of its liberation. We thus obtain great pressure. In order to subject the gas to low temperature, the upper part of the flask is connected with a long, thick copper tube. The same pressure will be found in it as in the flask, and a manometer affords a means of measuring the pressure with sufficient approximation for a first experiment. Around this tube, containing the oxygen under pressure, is placed a second

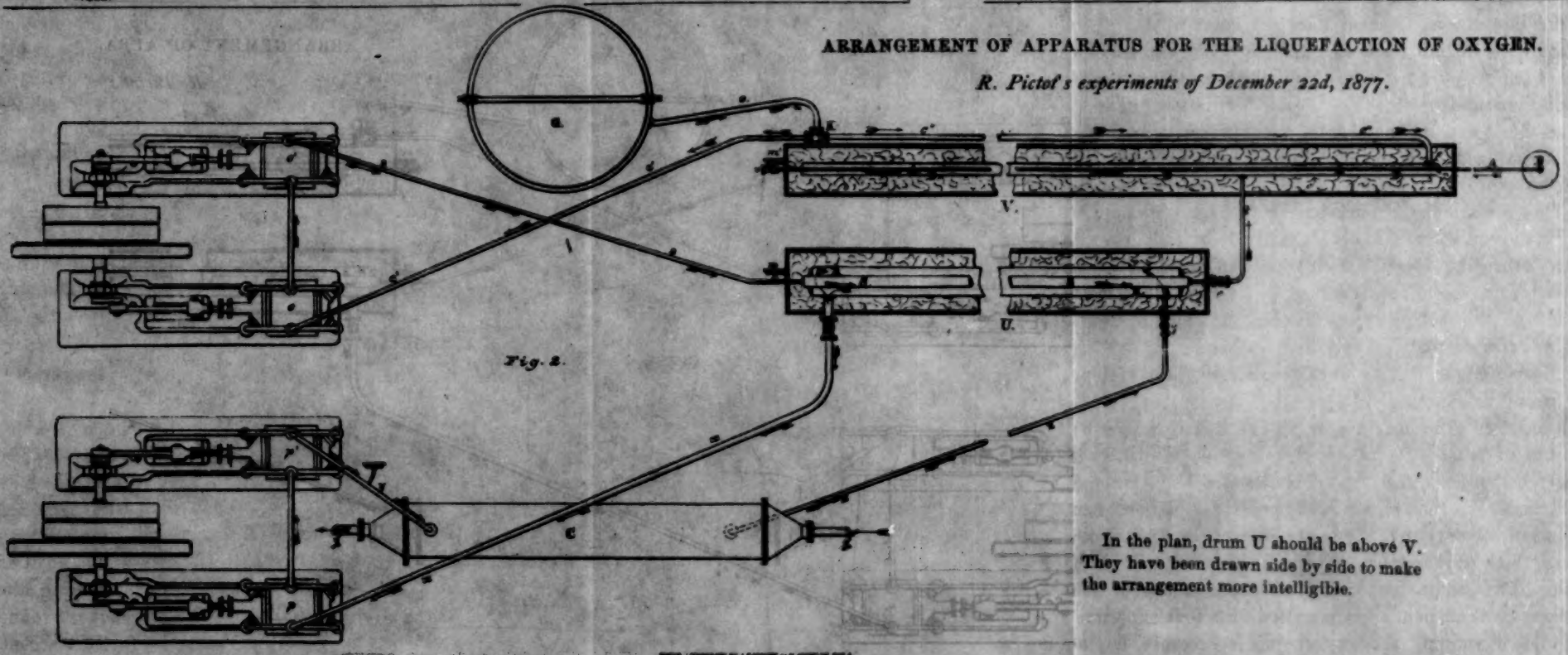
Fig. 1.



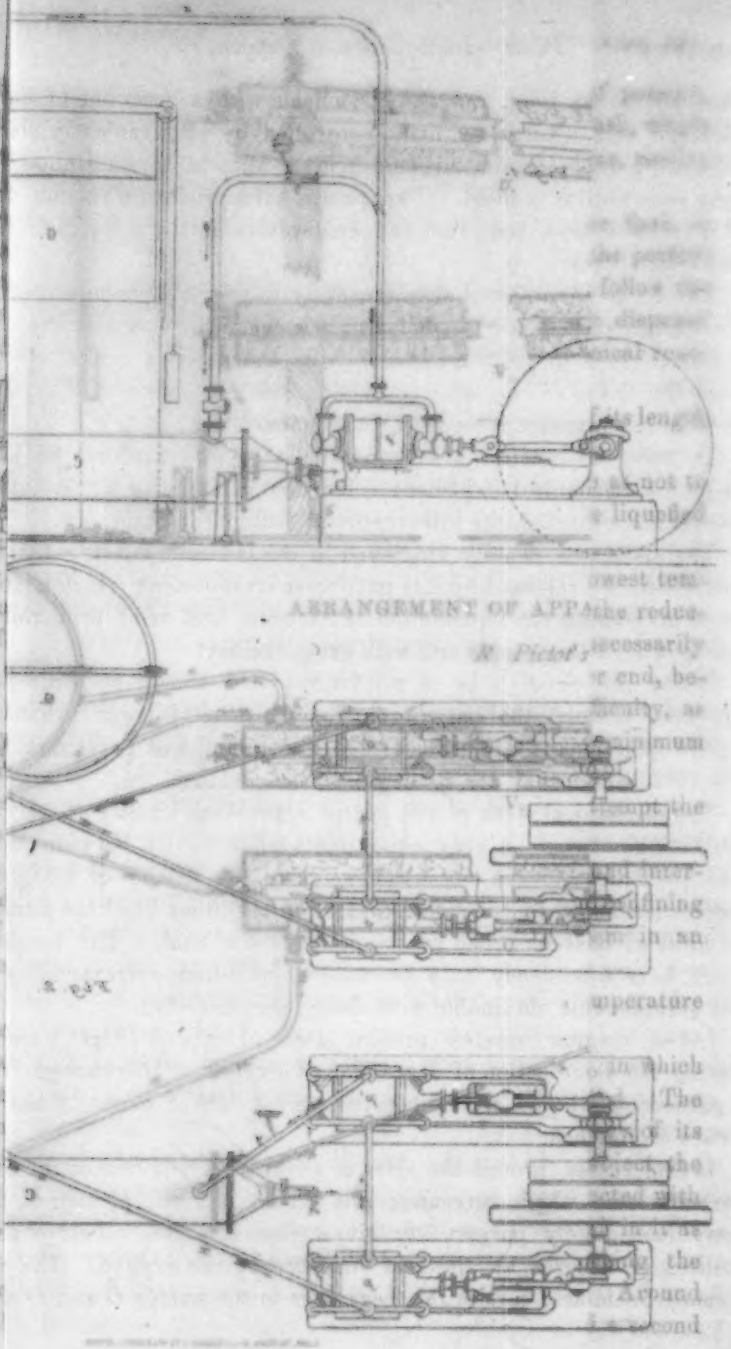
ARRANGEMENT OF APPARATUS FOR THE LIQUEFACTION OF OXYGEN.

R. Pictet's experiments of December 22d, 1877.

Fig. 2.



In the plan, drum U should be above V. They have been drawn side by side to make the arrangement more intelligible.



ARRANGEMENT OF APP

tube almost as long, and which connects with a reservoir of liquid carbonic acid. Little by little, controlled by a conveniently placed regulating cock, liquid carbonic acid is allowed to pass into this long tube until it is filled. Two pumps then produce a vacuum over this carbonic acid, and lower the temperature until the liquid freezes and crystallizes.

The oxygen, subjected simultaneously to this low temperature and the enormous pressure produced by the chemical reaction, then condenses; which is proven, either by the character of the jet ejected from the orifice of the tube containing the oxygen or by the variations in the pressure recorded by the manometer.

In order to obtain a great quantity of liquid carbonic acid, we employ a mechanical expedient consisting in securing a first fall of temperature through the intervention of sulphurous acid.

The apparatus usually employed in the laboratory being far too inefficient, are replaced by this particular arrangement, which enables us to accomplish the liquefaction of carbonic acid or of protoxide of nitrogen on a large scale and with great facility.

These two circulations of sulphurous acid and of carbonic acid are "permanent," that is, the entire quantities of vapor exhausted by the four pumps, are transformed into liquid, and pass back into the tubes where they are again volatilized.

The mechanical work of the pumps represents exactly the "cold producing cause." A very close relationship exists between these two quantities; on the one hand we have the number of kilogrammetres developed by the steam motor, on the other hand the number of units of heat absorbed by the production of cold. The temperatures have a tendency to a permanent condition, corresponding to the greatest cold obtainable with the means described.

Let us imagine ourselves present inside of tube *A* (Figs. 1 and 2) during the liquefaction of 1 gramme of oxygen. The change from a gaseous to a liquid state liberates a great deal of heat. What becomes of this heat?

It first passes through the sides of the tube *A* and acts on the solid carbonic acid which surrounds this tube. A small portion of this body immediately passes over into a gaseous state. This change utilizes or absorbs all the heat furnished by the oxygen. The gaseous carbonic acid carries this heat over to the pumps *O* and *O'* and

thence to the condenser *S*, there the carbonic acid resumes the liquid state and surrenders all the heat it abstracted from the oxygen.

The heat liberated by this second change of condition passes through the metallic sides of tube *S* and into the sulphurous acid in which this tube is immersed. Here, as before, a certain quantity of liquid sulphurous acid is evaporated, and acquires this heat by means of molecular motion. The vapors of sulphurous acid now pass over to the pumps *P* and *P'*, and are compressed in the condenser *C*. The last change of condition takes place, and the liquid sulphurous acid is reproduced.

The heat surrendered during this transformation passes through the metallic sides of the condenser *C* and into the current of water passing through the condenser. The water issuing from this apparatus, therefore, contains "all the heat surrendered by the oxygen," and this heat is drained off with this water of condensation. We have employed five successive changes of condition by this arrangement, to abstract the heat from the oxygen at a low temperature, and to transfer it mechanically to the drainage or waste water.

We think the above explanation will suffice to convey a sufficiently exact idea of the apparatus constructed, and will enable any one to easily follow the course of the experiments we will relate in the following chapter.

ON THE EROSIVE AND ABRADING POWER OF WATER UPON THE SIDES AND THE BOTTOM OF RIVERS AND CANALS.

By Clemens Herschel, Civil and Hydraulic Eng'r, of Boston.

[Continued from Vol. lxxv, page 403.]

Returning to a consideration of experiments made upon the power of currents to roll along materials, the year 1857 seems to have been the date of two sets of such. Mr. Thomas Login, M. Inst. C. E., in a short paper upon "The Floods of the Irrawaddy," printed in the "Proceedings of the Royal Soc. of Edinb., vol. 3, 1857, gives on page 475, the following table, reprinted in Stevenson's "Canal and River Engineering," 2d ed., page 315, as also in "Stevenson on

Harbors," page 165. These experiments were made in a small laboratory trough, in a stream "seldom exceeding half an inch in depth." If we are to judge from the fact that Mr. Login, in the many articles which he wrote on the "abrading and transporting power of water" in 1867–69, seems never to have once alluded to these experiments of his own, of ten or twelve years previous, we should conclude that he did not value them very highly; a conclusion that would be confirmed by a study of the arguments of these later articles.[1]

However, the following is the table:

MATERIALS.	Current required to move.	Rate of sinking in water.	
	FT. PER SEC.		
Brick-clay when mixed with water and allowed to settle for half an hour.	0·25	0·0095	Brick-clay in its natural state was not moved by a current of 2·1 ft. per second.
Fresh-water sand,	0·67	0·17	
Sea sand,	1·10	0·20	
Rounded pebbles, about size of peas,	2·00	1·00	
Vegetable soil,	0·90	(?)	

The other set of experiments made in 1857 are those by Thos. E. Blackwell, civil engineer, as Commissioner on Metropolitan Drainage, in the "accounts and papers" for 1857, ordered printed August 3d of that year. The table of results is on page 167 of the Appendix. It is reprinted in Beardmore's "Manual of Hydrology," on page 7, but omitting twenty-two sets of experiments. Though it might be inferred from the text that these experiments were made in a stream four feet wide by three feet deep, yet the drawing shows the experimental portion to have been only about eighteen inches deep. The channel was sixty feet long, and was made of rough but painted elm plank; the velocities were carefully and skilfully measured, and the record has been transmitted in exceedingly complete shape, so that these experiments rank very high among their particular kind. Fifty-three kinds of materials were experimented on, and the table is the record of four hundred and twelve experiments.

[1] Min. Proc. Inst. C. E., 1867–68, p. 471; *The Artizan*, 1869–30, and a series of articles later in the same volume: *Engineering*, 1869–1–412 and 1869–2–133; *The Engineer*, 1869–1.

Table showing the Effect of Running Water in Moving various Substances.

Description of Object.	Weight in oz. avoir.	Cubic contents in ins.	Specific grav.	Velocity of Current.																
				0 to 1·00	1·00 to 1·25	1·25 to 1·50	1·50 to 1·75	1·75 to 2·00	2·00 to 2·25	2·25 to 2·50	2·50 to 2·75	2·75 to 3·00	3·00 to 3·25	3·25 to 3·50	3·50 to 3·75	3·75 to 4·00	4·00 to 4·25	4·25 to 4·50	4·50 to 4·75	4·75 to 5·00
Brickbat	22·0	18·5	2·05	.....	.....	.....	.....	.....	.....	.....	.....	start	0·94	1·15	1·25	1·30	.....	2·14	2·31	.....
	16·0	13·6	2·03	.....	.....	.....	.....	.....	start	.....	.....	1·15	.....	.....	1·50	.....	.....	.....	2·31	.....
	9·0	7·33	2·12	.....	.....	.....	.....	.....	start	0·7	0·82	.....	1·20	.....	.....	.....	1·87	2·00	2·61	.....
	6·0	4·76	2·18	.....	.....	.....	.....	.....	.....	start	.....	.....	0·42	.....	1·2	.....	2·00	2·14	.....	.....
	3·0	2·59	2·00	.....	.....	.....	.....	start	.....	.....	1·00	.....	.....	1·50	.....	.....	.....	.....	.....	.....
	16·0	12·98	2·13	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	1·11	1·50	1·58	2·00	.....	.....	2·73
Building Stone (Oolite)	22·0	17·68	2·15	.....	.....	.....	.....	.....	.....	.....	.....	start	1·00	1·15	1·25	1·43	.....	.....	.....	.....
	9·0	6·70	2·32	.....	.....	.....	.....	.....	.....	.....	start	0·91	.....	1·15	1·20	1·25	1·87	.....	.....	.....
	3·0	2·39	2·17	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	1·36	1·43	1·87	.....	.....	2·22	.....
Chalk	22·0	18·54	2·05	.....	.....	.....	.....	start	.....	0·60	0·67	.....	1·20	1·30	.....	1·67	.....	1·76	.....	.....
	16·0	12·74	2·17	.....	.....	.....	.....	.....	.....	start	.....	1·00	1·11	1·50	.....	1·87	.....	.....	.....	.....
	9·0	7·78	2·00	.....	.....	.....	.....	.....	start	.....	0·93	.....	1·36	.....	1·87	.....	.....	.....	.....	.....
	6·0	5·18	2·00	.....	.....	.....	.....	.....	start	.....	0·92	.....	1·15	1·58	.....	1·67	2·14	.....	.....	.....
	3·0	2·39	2·17	.....	.....	.....	.....	.....	.....	start	0·75	0·94	1·03	.....	1·77	.....	.....	.....	.....	.....
Flints	16·0	10·37	2·67	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	start	.....	1·00	1·06	.....	1·56	1·84	.....
	9·0	6·05	2·57	.....	.....	.....	.....	.....	start	0·70	.....	.....	.....	1·30	1·50	.....	.....	.....	.....	.....
	6·0	4·11	2·52	.....	.....	.....	.....	.....	.....	start	.....	0·87	.....	.....	.....	.....	1·46	1·58	.....	2·00
	3·0	1·95	2·66	.....	.....	.....	.....	.....	.....	.....	start	.....	.....	1·07	1·36	1·43	1·76	.....	.....	.....
Coal	22·0	28·59	1·33	.....	.....	.....	start	.....	.....	.....	0·91	.....	.....	1·50	1·76	1·87	.....	.....	.....	.....
	9·0	11·69	1·33	.....	.....	start	0·54	.....	.....	1·11	.....	.....	1·67	.....	.....	2·07	.....	.....	.....	.....
	3·0	4·11	1·26	.....	.....	start	0·45	.....	.....	1·11	.....	.....	1·87	2·00	.....	.....	.....	.....	.....	.....
Clinkers	16·0	11·67	2·37	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	1·36	.....	.....	.....	.....	.....	.....
	9·0	6·05	2·57	.....	.....	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	1·15	1·50	.....	.....
	3·0	2·39	2·17	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	.....	1·50	.....	1·87	.....	.....	.....
Copper Slag	6·0	3·46	3·06	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	start	.....	1·07	.....	1·67	1·76	.....
	3·0	1·73	3·00	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	.....	1·21	1·76	2·00	.....	.....
	1·5	0·86	3·00	.....	.....	.....	.....	.....	.....	.....	start	0·79	.....	1·11	.....	1·76	.....	2·00	.....	.....

Limestone	5·0	3·02	2·86	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	0·94	1·11	.....	1·58	1·67	.....	.....
	3·0	1·73	3·00	.....	.....	.....	.....	.....	.....	.....	start	.....	.....	0·90	.....	.....	1·25	.....	1·43	2·00
	1·5	0·86	3·00	.....	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	1·00	.....	1·25	.....	.....
Oyster shells	2·87	2·60	1·91	.....	.....	.....	.....	start	0·29	.....	.....	.....	.....	0·94	.....	1·57	.....	.....	.....	.....
	1·12	0·86	2·24	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	0·38	0·86	1·12	.....	.....	.....	.....
	0·50	0·33	2·63	.....	.....	start	.....	.....	.....	.....	.....	.....	.....	.....	.....	1·50	.....	1·76	.....	.....
Slates	15·0	9·06	2·86	.....	.....	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	2·00	.....	.....	2·14	.....
	9·0	5·4	2·88	.....	.....	.....	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	.....	1·00	1·58
	4·0	2·38	2·90	.....	.....	.....	.....	.....	start	.....	.....	0·68	.....	.....	.....	.....	1·43	2·00	.....	.....
Nails	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	start	.....
Scraps of Iron (small)	.....	.....	.....	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Ginger Beer Bottle	18·87	14·50	2·25	.....	.....	.....	.....	.....	.....	.....	start	1·87	.....	.....	.....	2·14	.....	.....	.....	.....
Glass Bottle (broken)	19·0	12·12	2·71	.....	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	1·11	1·58	.....	.....	.....	.....
Brick on dab of Clay	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	start	about	6·00	.....	.....
Granite (broken)	6·50	4·22	2·66	.....	.....	.....	.....	.....	start	.....	0·65	1·00	.....	1·15	1·25	.....	1·76	.....	.....	.....
	3·0	1·94	2·67	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	.....	.....	1·00	1·44	.....	1·87	.....
	1·50	0·97	2·66	.....	.....	.....	.....	.....	.....	.....	.....	start	.....	1·11	.....	1·30	1·50	2·00	.....	.....
Boulders	11·87	.....	.....	.....	.....	.....	.....	start	.....	1·08	.....	1·30	.....	.....	.....	.....	1·53	.....	.....	.....
	5·87	.....	.....	.....	.....	.....	.....	.....	.....	start	1·11	.....	.....	1·67	.....	.....	2·14	.....	.....	.....
	3·31	.....	.....	.....	.....	.....	.....	.....	.....	.....	start	.....	1·50	.....	2·00	.....	2·31	.....	.....	.....
Sewage deposit	.....	.....	1·30	.....	.....	start	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Road Scrapings	.....	.....	1·78	start	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Gravel, ½ inch	.....	.....	1·41	.....	.....	start	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
" ¼ inch	.....	.....	1·46	.....	.....	.....	.....	.....	.....	start	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sand (yellow)	.....	.....	1·81	start	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
" (green)	.....	.....	1·81	start	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

NOTE.—The figures in the table show the velocities, in feet per second, with which the various substances moved after they had started.

Says Mr. Blackwell: "These experiments allow the following inferences to be drawn: 1. For objects of the same character, the velocity required to start them, increased with the mass of the object. 2. For different objects the velocity increased with the specific gravity. 3. That according as the object assumed a form approaching a sphere, the less velocity it took to move it; whereas, a flat object, like slate, required a considerable current before it became disturbed from its position. And 4. As the velocity of the current is increased after an object is in motion, the velocity of such object increases in progressive ratio.

It is well to observe at once, that a velocity which will start an object will (when constantly maintained, and no accidental circumstances occur to prevent it,) never allow such object to deposit in the stream. Layers of the different objects were submitted to the action of the current, and the general results proved that the velocity required to remove them was considerably above that which would have been efficient in the case of a single object.

As a general conclusion, it may be observed that a velocity from 2 feet to 3·5 feet per second will remove all objects of the nature and dimensions of those that are likely to be found in sewers."

If the writer were to comment on these remarks, it would be to the effect that though the experiments do not, of course, disprove the very rational inferences above cited, and which would also result from careful *a priori* reasoning, they certainly show no regular laws of the kind indicated. It would be impossible to evolve from them, for example, a formula showing the relations between mass and velocity, or between specific gravity and velocity. In saying this, no fault is intended to be found with the experiments, but it is said for the purpose of pointing out the want of regularity in the action of currents of this kind and under such circumstances. The experiments were made to test whether, and they prove that "a velocity from 2 feet to 3·5 feet per second will remove all objects of the nature and dimensions of those that are likely to be found in sewers." Further than this, little can be concluded from them.[1]

[1] For the benefit of American readers, attention should be called to the fact that the oyster-shells spoken of in the table are puny little things, 2·5, 3, and 3·5 inches long. To move a "Stony Creek" or other prime oyster-shell, 9 or 10 inches long or more, would probably bother most sewer velocities.

An interesting point that seems to have been overlooked by experiments on artificial channels, or which they have as yet been unable to experiment on, is the effect of the inclination of the bed on which the materials to be rolled along are resting. In all the experiments made, this seems to have been very nearly horizontal, and such would be, approximately, the beds of all water-courses to which the experiments may be made to apply. But it is different with the *banks* of canals, and it is very conceivable that they would be easier affected by a simple straight current than the bottom of a canal or river, and that the current would cause certain portions of these banks to slide down to the bottom. We know, indeed, that waves have been observed to have an effect of this kind. In the Min. Proc. Inst. C. E., 1866–67, in the discussion on the use of steam power on canals, also quoted in Stevenson's "Canal and River Engineering," page 24, it is stated that on the Gloucester Canal, after the introduction of steam towage, the waves and other commotion in the canal (that were a result of the increased speed of the vessels passing through) caused the soft mud, which had formerly collected on the banks, to slide down these slopes, and kept them clean; in this case proving a benefit, for it had formerly been difficult to remove this mud with the dredge, for fear of injury to the banks; but the dredge could dig it up without such fear from the bottom of the canal.

There remain a number of data to be mentioned, having reference to the size and the behavior of materials as actually found in the beds of streams. On page 473, Min. Proc. Inst. C. E., 1867–68, Mr. Thomas Login says: "Experience on the Ganges Canal has shown that this (to have the deposits balanced by the abrasions) requires a mean velocity of about 3·75 feet per second, with a surface slope of a little less than fourteen inches in the mile." And on page 479, Mr. Login gives a "table showing approximately the sections and slope probably best adapted to irrigation canals and water-courses for Northern India." Coming as it does from a gentleman of long experience in this particular branch of the profession, it is entitled to serious consideration, to say the least. It is for each engineer to note the wide difference between the data given by Mr. Login and those derived from the trough experiments of Dubuat, and to decide to which he proposes to give the greater weight.

The following is the table above referred to:

Table

Showing Approximately the Sections and Slopes Probably Best Adapted for Irrigation Canals and Water Courses for Northern India.

Cubic feet of discharge per second.	Calculated Sections.					Proposed Sections.			Side slopes of channels.	REMARKS.
	V, Mean velocity ft. per sec.	*H*, Hydraulic mean depth.	Breadth of channel at bottom.	Depth of water with full supply.	Slope of surface of water. Inches per mile.	Breadth in feet at bottom.	Depth in feet with full supply.	Slope of water surface, full supply.		
CU. FT.	FT.	FT.	FT.	FT.	IN.			IN.		
50	2	2	2½	4	15	2	4½	16½	1 to 1	Calculated on Beardmore's formula: $\frac{11\sqrt{H \times S}}{12} = V$, where: H = Hydraulic depth in feet. S = Fall in ft. of surface of water per mile. V = Mean velocity in ft. per sec. In no case should the mean velocity exceed 4 ft. per sec, 3¾ probably being the safe limit, and not less than 2¾ ft. for the main channels. Keeping in mind that the greater the velocity, the cheaper the section in deep digging.
100	2¼	2½	4½	4¾	14½	4	5¼	16	1 to 1	
250	2½	3⅓	15	5	13½	13½	5½	14⅝	1 to 1	
500	2¾	4¼	27½	5½	13	25	6	14½	1 to 1	
1000	3	5	50	6	13	45	6⅞	14⅛	1 to 1	
2000	3¼	6	77½	7	13	70	7⅞	14⅓	1½ to 1	
3000	3½	7	95	8	12¾	85	8⅛	14	1½ to 1	
4000	3½	7½	121½	8½	12⅜	110	9⅓	14	1½ to 1	
5000	3⅔	7⅔	147½	8½	12½	130	9⅔	13¾	1½ to 1	
6000	3¾	8	170	8¾	12½	150	9⅞	13¾	1½ to 1	

On page 509 Mr. Login gives these additional data concerning the Ganges Canal.

No. of mile.	Point of observation.	Mean velocity. Ft. per sec.	Discharge. Cu. ft. per sec.	REMARKS.
1st.	Below the Regulator near Hurdwar.	5·10	6710	At the Regulator the water was 9 ft. deep. The bed was composed of pebbles, and had a slope of 2 ft. per mile, the water was quite clear.
19th.	Over the Solani Aqueduct at Roorkee.	4·48	6283	The depth of the water over the floor of the aqueduct was 8·25 ft. The water was slightly turbid.
50th.	At the head of the Futtigurh Branch above the Regulator.	3·46	5279	There was silt on the floor of the Regulator, and the water was very turbid.

And on page 544, Mr. J. T. Harrison, M. Inst. C. E., gives the following:

Name of River or Canal.	Length of Canal in Miles.	Fall per Mile.	Velocity.		Discharge per day, in Gallons.	Remarks.
			Ft. per sec.	Miles per hour.		
		IN.				
Ganges Canal to Nanoon.....	180	.....	.....	.....	.....	....
Cawnpore Branch	170	14	3·75	2·2	2.700,000,000	....
Etawah	180	... .	.....	.....	.....	....
Ditto.....	.....	17	.....	3·0	.....	Dangerous cutting bed.
	.....	15	.....	2¾	.....	Slightly "
	.....	13·8	.....	2¼	.....	Silting up.

On page 545, Mr. Login observed "that the slope of the Ganges Canal was originally projected at fifteen inches in a mile, and the calculated velocity of the current was four feet per second. In the year 1860, when he took charge of the works, the surface slope exceeded sixteen inches, with a mean velocity of 4·5 feet per second, and the bed was being eroded to a dangerous extent; this he had reduced to about fourteen inches in the mile, and the mean velocity of the stream had fallen to 3·75 feet per second. With this reduced velocity the bed began to silt up, and it had continued so for the last five years; therefore, he believed the proper slope and velocity had been obtained."

On page 541, Mr. Harrison states: "The Thames in some parts afforded an excellent illustration of the importance of maintaining sufficient inclination and velocity to enable the river to carry off mud. He had found that for several miles above Oxford the natural fall of the Thames valley was about fourteen inches in the mile, the minimum inclination at which, apparently, in this country as in India, large rivers could carry off mud. The river Thames formed a winding channel through this valley of deposited mud; by the introduction of locks, the inclination was reduced from fourteen inches to eleven inches per mile, consequently a considerable part of the Thames above Oxford was silted up, so that a boat drawing eighteen inches of water could not pass up the river."

In the article by M. Fargue, in the *Annales des Ponts et Chaussées*, 1868, already mentioned, it is stated that the mean width of the

Garonne, near Langon, is about five hundred and ninety feet. At low water the slope is about sixteen inches in the mile, though as much as eighty-nine inches to the mile in some places. The depth averages about ten or eleven feet. On an average of twenty-six years there were:

66·5 days of low water in each year,
195·0 days of mean water,
81·0 days of "bank full,"
20·8 days of ordinary freshet,
1·7 days of extraordinary freshet.

During these twenty-six years the average discharge was about 25,000 cubic feet per second (about 687 cubic metres), whence, as a grand mean for twenty-six years and for all depths, the velocity would average about four feet per second.

The stretch of river under examination was about fourteen miles long, and the bed of this portion of it consisted of pebbles from 2·0 to 3·4 inches in diameter, mixed with thirty-three to fifty per cent. of sand. It had been in a virtually constant condition for twenty odd years.

RESULTS UPON THE RHINE.

Miles below Basel.	Pieces of gravel to the foot: — ∛ pieces, in one cubic foot.	Weight of largest piece. Lbs.	Velocity: Feet per second, at high water.	Slope in inches per mile.
2·5	8·4	13·5	12·	63·
20·0	10 7	10·5		
34·5	11·5	6 4		
58·5	?	4·9		
90·0	12·4	3·3	10·	39·
115·0	16·9	2·2	8·	25·
165·0	18·1	0·2	Aver. 5·	Aver. 9·

Professor Henry Sternberg, Director of the Polytechnic School of Carlsruhe, and a practicing engineer for fifteen or twenty years until he became professor in 1862, in an article in the Berlin *Zeitschrift für Bauwesen* for 1875, page 495, on the "Profiles and cross-

sections of rivers bearing gravel," gives the foregoing table (the original in metric measures) of data concerning the Rhine, from Basel to Mannheim. Some data of slope and velocities are added, taken from a historical account of the improvement of this portion of the Rhine, published by the Engineering Department of the Grand Duchy of Baden. The Rhine flows on this length of one hundred and sixty-five miles, mainly between artificial banks, from two hundred and forty to three hundred metres, seven hundred and ninety to nine hundred and eighty feet apart; its maximum depth is about twenty-nine or thirty feet; average depth about sixteen or seventeen feet.

Finally, J. Schlichting, an engineer of the Prussian government, in charge of works upon the Memel, in the same journal for 1877, page 86, in mentioning Prof. Sternberg's article, says: "The mean velocity at the bottom of the Memel, as derived from the current measurements taken in five cross-sections, varied from 1 foot to 1·6 feet per second. On this part of the river the bed consists of fine sand, 'pin gravel,' and pebbles of the size of a pea, all mixed up; occasionally, larger pebbles are found, the size of a bean, say. This sand, pin gravel, and pebbles remain in constant motion, even at low water stages of the river, as may be inferred from the continual changes in the channel and the shoaling up of portions of it. This last operation is often completed in a few days, whence it may be inferred that the velocity of motion of these materials is quite appreciable." If it may be permitted to point out the somewhat curious course of reasoning in these sentences, the writer would call attention to the circumstance that the facts stated prove the deposit or cessation of motion of the materials on the bottom of the river, quite as much as they do that of their continuous movement. In other words, a bottom velocity of 1 to 1·6 feet per second, corresponds to a general movement of sand, pin gravel and pea pebbles, but it also corresponds to a deposit of the same class of materials. Or are we to infer that shoaling and scouring are in equilibrium at these velocities?

This case very well illustrates the difficulty of expressing a complex relation of this sort in figures. As an additional illustration, it may be instructive to consider the following table, compiled from data that have been given in this paper.

Diameter of pebble in inches or as described.	AUTHORITY.									
	Funk. Large rivers.		Dubuat. Trough expts.	Umpfenbach Small brooks		Login. ½ in. depths.	Blackwell. 48 × 18 inches of channel.	Sternberg. River Rhine.	
	Surface veloc. observed.	Bottom veloc. calculated.	Bottom veloc. rudely measured.	Surface veloc. observed.	Bottom veloc. calculated.	Bottom veloc. measured.	Bottom veloc. measured.	Surface veloc. observed.	Bottom veloc. calculated.
	Pebbles move when Velocity is in Feet per Second.								
Pa sits	.....	.....	0·67	.....	.....	2·0	.....	.....	.....
0·25	.....	.....	.....	.....	.....	.....	1·25 to 1·50	.....	.....
0·5	.....	.....	.....	.....	.....	.....	2·25 to 2·50	.....	.....
0·67	.....	.....	.....	.....	.....	.....	.....	(5·0)	3·0
1·00	.....	.....	2·00	(3·1)	2·5	.....	.....	.....	.....
1·5	.....	.....	3·00	.....	.....	.....	.....	(10·0)	6·2
2·0	(5·6)	3·1	.....	(5·2)	4·0	.....	.....	.....	.....

The conclusions of the writer may be summed up in the following paragraphs:

I.—Water, when in motion, acts or tends to act upon its channel in two ways. 1. By direct friction, tending to drag materials along its bed, or down its banks, if these have a sufficiently steep side slope; and 2. By lifting up materials, holding them in suspension, and thus carrying them along in the body of the current.

1. It is difficult to determine at what velocities any one kind of material will commence to move by direct friction of the water. It must depend on the specific gravity of the material, on the shape of its individual parts, on the nature and inclination of the bed it is to roll on, and to measure this velocity with any accuracy, the moving water must be free from all whirlpools or other relative motion of its particles among themselves, tending to lift up and carry off the material with which the experiments are being conducted. The effect of the simple friction of a stream of water upon its bed and banks is not a source of danger; its action is very slow, and it has never been shown to be of a dangerous character in any instance. It is apt, however, to produce shoals, similar to submerged, moving dunes (as in the Wisconsin River, above referred to), and thus to obstruct navigation, in the case of clear water rivers, flowing in a sandy bed, and in time of low water.

2. The exact force and other determination of the inner movements of the particles of water among themselves which abrade and erode banks and beds, lift up and transport materials, defies calculation or expression by formulæ in the present, or any at present conceivable state of hydraulic science. The effect of these inner movements must remain a matter of judgment in every especial case.

II.—For either kind of motion, and for every amount of it, there is a limiting size of individual objects of a certain specific gravity which will no longer be affected by such motion; therefore, just so soon as the beds and banks of a water-course are covered with bodies of this size and quality, those smaller and lighter having been washed away or covered up, the bed and banks must remain permanent.

Trouble, by reason of too much erosion, seems to have been confined, generally, to cases of undermining bridge piers and similar masonry or other structures placed in running water; the remedies for too much erosion have been either to diminish the velocity, and at the same time with it the relative motion of the particles of water among themselves, or the latter alone, by taking pains that the flow of the stream shall be as smooth, regular and uniform as possible; or else to protect the parts that suffer from erosion by stone pitching, fascines, and by similar well known kinds of covering.

Trouble, by reason of the shoaling up of channels, has been remedied by stopping the erosion, whence comes the material which was being deposited; this called for the same remedies, therefore, as the difficulty last considered. But when it was a case of the shoaling up of a canal, fed from a silt bearing river, or any similar case, in which the erosion of material could not be prevented, then reliance had to be placed upon an opposite course of treatment, and by an increase of absolute and of relative velocity, the scouring had to be increased until there was a balance between the tendencies to deposit and to deepen; or if it was the case of a river, shoaling from the effect of simple friction of the water on its bed, or a river in which considerations of high and low water volumes, and other such considerations, prevented the application of remedies proper enough in a canal, but inapplicable to the case in hand, the engineer may have arrived at a conclusion often reached before, namely: that the difficulty was one to be avoided rather than remedied. A scheme of "slack-water navigation," by means of fixed or movable dams, or a

lateral canal, would then take the place of a river improvement. It would result from these considerations that canals are easier managed than rivers; and canals that carry clean water naturally are easier managed than those that come already loaded with silt into that part of their channel which is to be taken care of.

It has often been spoken of as a curious freak of nature that brooks and rivers running through low lands should still further diminish their fall per unit of length by forming curves and serpentines; but if it is true that curves and bends are the most potent cause of whirlpools, and other such commotions of the water that rivers are subject to, and that these commotions are the prime agencies in the abrading and transporting power of these rivers, then this matter has the appearance of a very beautiful feature in the economy of nature. For by no other known means could these rivers acquire this power of abrading and of transporting matter, and thus enabling themselves to maintain their channel and their very existence.

FUTURE WATER-SUPPLY OF PHILADELPHIA.

(Second Paper.)

By Henry P. M. Birkinbine.[1]

In my former paper on the future water-supply of Philadelphia, the various sources, with their present and prospective and comparative purity and their volume, were presented for your consideration; these were the Schuylkill River, Delaware River and the Perkiomen Creek.

In this paper it is proposed to compare the several means suggested for securing the future supply from the above named sources.

Schuylkill River.

1st. Increasing the water-power at Fairmount, by store-dams to keep up the flood-water and utilize it for power in times of drought.

In the former paper it was shown that the minimum flow of the Schuylkill past Fairmount was 200,000,000 gallons per day, that the mean daily flow when free from storm-water was 650,000,000 gallons

[1] Read before the Franklin Institute, May 15th, 1878.

per day, and that the maximum flow, or a mean of all the water flowing in the stream including storm-water, was an average of 1,665,000,000 gallons per day; but 1,000,000,000 per day of this is not utilized, it is wasted over the dam during freshets.

What is proposed to be done is to construct store-reservoirs in the drainage area of the river to retain the storm-water and use it to make up deficiencies of low water.

In the report of the special committee of the Commissioners of Fairmount Park, on the preservation of the purity of the water-supply, 1867, page 13, the annual average of the three years (1863-64-65) is given as equal to a daily flow to waste (after supplying the city) of 4,242,416,396 gallons; and that this waste power would pump an average of 303,000,000 gallons per day. The amount of water which the special committee assert as flowing to waste, or over the dam without being employed in pumping, would require an annual precipitation many times greater than any of which we have record, indeed, nothing but such an amount of rain as falls in some tropical regions would produce so great a flow of water in the Schuylkill. The acceptance of this statement, without examination (no doubt by reason of the authority under which it is given to the public) has led to some of the schemes which have been brought out for supplying large additional quantities of water by the Fairmount water power.

Statements like the above require no further attention; and we will, therefore, assume the quantities given in my former paper to be correct, namely:

Minimum daily average, 200,000,000 gallons,

Mean daily average, 650,000,000 gallons,

Maximum daily average, 1,665,000,000 gallons.

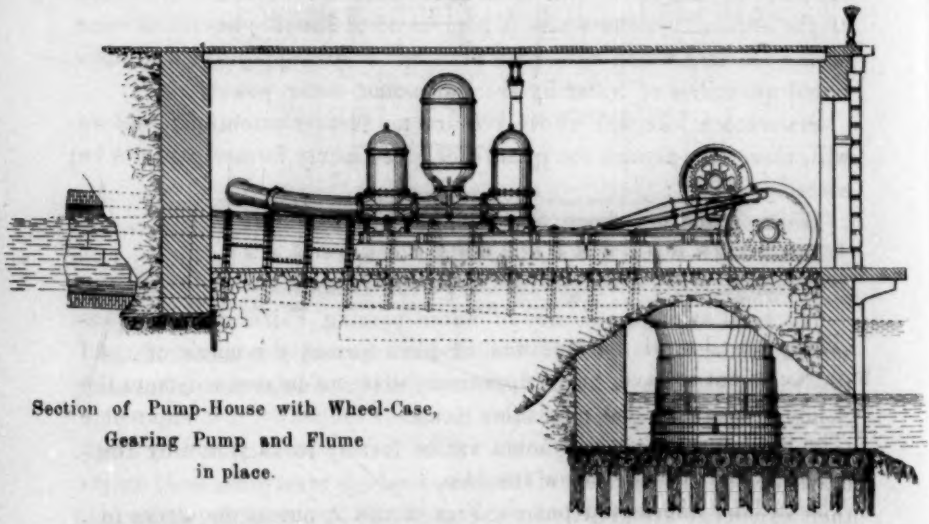
The total average quantity of water passing Fairmount is represented by the last quantity which I have termed the maximum, and this will, therefore, indicate the utmost that can be secured from the Schuylkill by any system of store dams. Practically, it is impossible to utilize all of this water; some will be lost by leakage and by evaporation from the surface of the impounding reservoirs, and, unless their capacities are greatly in excess of the ordinary requirements, some will be wasted by extreme freshets, so that the total quantity of water which could practically be utilized at Fairmount, would not exceed 1,250,000,000 gallons per day. Estimating that it requires 15 gallons (the quantity generally assumed) to raise one gallon into

the city reservoir. This would represent an average of 83,333,333 gallons per day, as the maximum supply of water procurable by water-power with the aid of adequate store dams, not 303,000,000 gallons, as represented by the report of the Park Commissioners.

Pumping Apparatus at Fairmount.

There is but one of the original pumps and wheels remaining in the Fairmount works. This consists of a low breast (under shot) wheel propelling a double-acting piston pump. The pump is operated by a crank wheel on the main shaft of the water wheel. The wheel is 15 feet in diameter and 15 feet face; the pump is 16 inches in diameter, with 4 feet 6 inches stroke of piston. This is a simple and desirable arrangement, and is as efficient as any of the more recent motors and pumps. This wheel is stopped during high tide, and cannot utilize all the fall, a portion of it being lost at low tide; notwithstanding this, the old breast wheels pumped more with the same expenditure of power than the turbines and pumps now in the works, as will be shown.

Fig. 1.



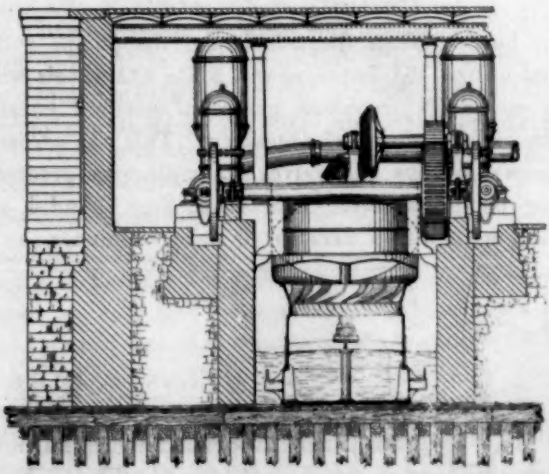
Section of Pump-House with Wheel-Case, Gearing Pump and Flume in place.

The reasons which led to the adoption of turbine wheels were: they could be better protected from ice; they could be run during the entire time, and, when the tide was out, the total fall of the water could be in part utilized. How to secure all these advantages,

and the kind of motor to be employed, required careful investigation, and a series of experiments was instituted with various forms of turbine wheels.

A simple testing apparatus was erected at Fairmount works; it was not what would be termed a strictly accurate apparatus, but it was so arranged that the different wheel builders, with but ordinary knowledge of figures, could make their own measurements and calculations. Notwithstanding the imperfections of this apparatus, the tests were more reliable and better presented the peculiarities of the different wheels than those instituted at the Centennial Exhibition, in 1876, with such a display of pretended accuracy.

Fig. 2.



Transverse Section of Pump-House, with Turbine, Gearing and Pumps. The lower part of Wheel Case shown in Section, exhibiting Guide-Cams, Wheel and Gate.

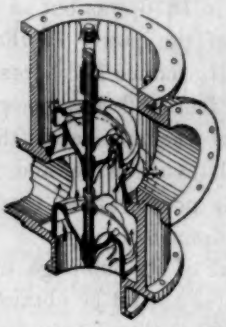
The plain Jonval Turbine was adopted, not only because of the high coefficient it gave, but it appeared better calculated to meet all the requirements of that particular location.

The head and fall at Fairmount varies from 8 to 14 feet, with the rise and fall of the tide below the dam.

The turbine wheels and pumps, Figs. 1 and 2, put in the works in 1860, were under my own supervision, but are not now satisfactory to me. These wheels are 9 feet in diameter, with an area of issue equal to 1700 square inches, and will develop, when the tide is in and the fall is 8 feet, 108 horse power; when the tide is out, and the fall 14

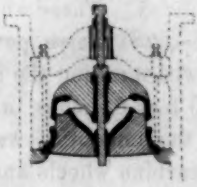
feet, 250 horse power; at mean tide, 174 horse power. These wheels, of which there are three, each operate two double acting piston pumps, 18 inches diameter of cylinders, and 6 feet stroke of piston. They were constructed to pump into Corinthian Avenue Reservoir, 115 feet high. The work to be done is constant, while the power of the wheel varies with the rise and fall of the tide. The only direct means of utilizing this varying power was that of the difference in the velocity of the wheel due to the changing head; but this would not absorb the entire power. The pumps were so proportioned and geared as to absorb 105½ of the 108 horse power of the wheels when the tide is in; when the pumps made 23 strokes per minute. At mean tide, the pumps make 29 strokes and absorb 131 horse power of the 174 horse power which the wheels would give under that head. When the tide is out the pumps will make 35 strokes, and utilize 161 horse power, while the wheels will produce 250 horse power. It required pumps of peculiar construction to allow of the high piston speed necessary. This was accomplished by making the water-ways and valves of ample size, greater than the area of the pump cylinder. The valves, Figs. 3 and 4, are double-beat Cornish, made with a dash pot or water cushion, so as to prevent

FIG. 3.



Isometrical Section of Valve-House, showing valve in place.

FIG. 4.



Double-beat Cornish Valve, with Birkinbine Patent Water-Cushion.

the faces coming in violent contact when closing. These valves, when in order, will close noiselessly, even when the pump pistons move at the rate of 250 feet per minute.

With this arrangement there was an average loss of 43 horse power at mean tide, and when the tide is out, of 89 horse power, or rather so much of the power of the wheels cannot be utilized, and is, therefore,

to a great extent wasted. The amount of power actually utilized, as exhibited by the water pumped per hour into the reservoirs during 1876, was but an average of 105·3 horse power. The gates for controlling the wheels are simply cylinders placed below them on the draft tubes, and are raised to allow the escape of the water; the distance moved is the only means of controlling the quantity of water issued by them. The excess of power in the wheels above that which can be exerted upon the pumps is expended upon the friction produced by the gates retarding the flow of the water issuing from the wheels.

The arrangement of the machinery of 1870, is simply a repetition of the defects of the apparatus of 1860, with this difference, that the pumps are run to full working speed when the tide is in, and on account of defective arrangements of parts, the piston speed cannot be increased. The loss of power in these pumps is, therefore, much greater. Other forms of wheels might have been employed, such as are now well known and are controllable, so that a part of the power could be employed without materially affecting their coefficient of useful effect, or some arrangement made by which the power wasted could be utilized.

The amount of power employed in raising water, as shown by the water pumped per hour into the reservoir in 1876, was but an average of 105 horse power, less than one-half of the power of the wheels being utilized. These wheels at 8 feet will produce 143 horse power; at 11 feet 231 horse power, and at 14 feet 330 horse power. So that notwithstanding the increased size of the apparatus (the wheel being 10 feet 6 inches in diameter, 2250 inches issue, and 22 inch pumps), the amount of water raised is no greater than that by the smaller turbine wheels and pumps above described.

As long as the city depends for so much of its pumpage upon the water power at Fairmount, the utmost value should be obtained from it; and the subject has appeared so important that I have called the attention of the Water Department to these defects and the possible remedies.

The average amount of water furnished per day by Fairmount works in 1876 was 22,809,066 gallons. The maximum daily average for a month was, in May, 28,142,199 gallons.

With properly arranged and managed machinery, a daily average of 35,000,000 gallons could be pumped.

The wheels now in these works can absorb more than the average flow of the river. Little can, therefore, be gained by increasing the number of wheels. Having conceded the means of applying the power, we will consider

Impounding Reservoirs.

The special committee of the Park Commissioners suggested that a series of large store reservoirs be constructed to increase the water power at Fairmount, and presented estimates for doing the work, which made the plan appear feasible. But they estimate that a reservoir capable of containing 1,000,000,000 cubic feet (nearly 7,500,000,000 gallons) could be constructed for $200,000, a sum insufficient to purchase the necessary land which would be flooded, and pay for mill powers destroyed, if the available sites for such dams exist.

James F. Smith, C. E., Engineer of the Schuylkill Navigation Company, has presented a carefully thought out plan of storage reservoir. He proposes to raise some of the dams belonging to the Navigation Company, and to build others on the main stream, and also store reservoirs on the upper tributaries. No estimate is presented of the cost of this arrangement. Mr. Smith calculates that 4,595,243,931 gallons could be impounded by these dams and reservoirs. This, if utilized in pumping at Fairmount, would only raise 300,000,000 gallons into the city reservoirs, or taking 70 days of drought, it would add an average of about 4,000,000 gallons per day to the pumping power at Fairmount, an amount of water inconsiderable when compared with the demands of the city. This would require the purchase of eight dams, the raising of several more, and the construction of four new dams in the main stream and store reservoirs in the mountains. This plan represents about all that can be secured by impounding storm water for power.

There is probably no site in the drainage area of the Schuylkill where a large impounding reservoir could be as cheaply or as safely constructed as that on the Perkiomen, suggested for the gravitation works. The cost of this dam was estimated at $500,000. This reservoir could be utilized to store and furnish 5,000,000,000 gallons. This would furnish power to pump an average of, say, 4,500,000 per day during a drought of 70 days' duration.

2. ***Purchasing the water power created by Flat Rock Dam.***—All the available power, except that required for the passage of canal boats, is now fully employed, and is leased by 13 different manufacturing establishments. This is equal to one thousand horse power, and produces an annual rental of $43,100, which capitalized at six per cent. would equal $718,333.33, but it would also be necessary to assume the cost of changing the power of the various establishments from water to steam, which would probably bring up the purchasing value to one million dollars. To this must be added the expense of utilizing this power for pumping water, wheel houses, wheels, raceways, pumps, pumping mains, etc., estimated by the Commission of Engineers, at $725,000. No more figures are necessary to show that this would make a much more expensive pumping arrangement than steam apparatus. When to these estimated expenses the annoyance of the co-occupation of the river with the Navigation Company, the delays and losses incident upon freshets and drought in the stream are taken into account, this, as a source of increased supply, loses all its supposed value.

3. ***Raising Fairmount and Flat Rock Dams.***—Raising Fairmount Dam, say, two feet, could be done at a comparatively small cost; but the damages by overflowing and backing up the water would be great, notwithstanding the city is the riparian owner of most of the property affected.

The two feet additional would add 18 per cent. to the power of Fairmount pumps, but to utilize this would require machinery adapted to the increased head. The two feet added to the height would store 200,000,000 gallons; but this could not be utilized without impairing the power by drawing down the head. The additional supply by the increased head would be but from 4,000,000 to 5,000,000 gallons per day.

To raise Flat Rock Dam would require a new structure and large expenditures in head-gates and races. The value of property destroyed by the water—in land, factories and other buildings, in roads, railroads, etc.—would be very great.

If both of these powers were utilized for pumping water for the city—Fairmount Dam raised two feet, and Flat Rock Dam raised four feet—a daily average of 90,000,000 gallons might be pumped by water-power.

4. *Increasing the Capacity of the Works by Steam-Pumping Apparatus.*—In the report of the Water Department for 1876, p. 15, the cost of pumping an average of 50,000,000 gallons per day is given, one-half, by water-power, costing $18,000; the other half, by steam, costing $162,000; making a total of $180,000 per annum. From this data it is estimated that the cost of 100,000,000 galls. will amount to $504,000 per annum, one-fourth by water, three-fourths by steam. This would be at the rate of $720 per annum for each million gallons per day by water-power, and $6,480 per annum for each million gallons per day by steam; but this estimate only takes into account the direct expenses of running the works, viz., salaries, supplies and ordinary repairs. There are other expenses incident to furnishing the water, such as supervision, keeping buildings, grounds and reservoirs in order, renewals and extraordinary repairs. Taking these into account, the cost of furnishing the water supply to the city, in 1876, amounted to $298,718.71. Using these figures as a basis, the cost per annum of supplying 100,000,000 gallons per day, would be over $800,000. In this there is no estimate of the cost of the additional machinery which would be necessary to furnish the increased supply of an average of 50,000,000 gallons per day. It is not probable that this can be done, with economical and efficient machinery, so as to bring the annual cost of furnishing daily average of 100,000,000 gallons below $1,000,000 per annum.

The additions made within the past ten years, which have been from 20,000,000 to 25,000,000 gallons per day, have cost the city from $6,000,000 to $6,500,000, or, say, $250,000 per 1,000,000 gallons of increase per day. If the cost of the enlargement of the works be estimated upon this basis, an average increase of 50,000,000 gallons per day will cost $12,500,000.

The proposition which a responsible firm in this city made to Councils, for furnishing and operating a pumping-engine for five years, for the saving in the expense, as compared with Belmont Works, shows that there is great room for improvement in the pumping apparatus, and in cost of maintaining them.

Delaware River.

The Commission of Engineers, in their report, present three plans for securing a supply from the Delaware River, by pumping.

1. *New Hope by Conduit.*—This plan proposes pumping a part by water-power, and will require the purchase of the power at that point. The distance to East Park Reservoir is 40 miles. The Commission estimate the cost of this plan (capitalizing the cost of steam-pumping) to be $23,000,000.

The supply is given at 75,000,000 gallons per day.

2 *New Hope by Canal and Conduit.*—In this project 31½ miles of the Delaware division of the Pennsylvania Canal would be purchased. The entire length of the canal, conduit, etc., to a reservoir at Lardner's Point, would be 43 miles. This, with the cost of pumping capitalized, is estimated at $22,500,000.

3. *Scudder's Falls by Conduit.*—This scheme would require the purchase of the Trenton water-power, the erection of a dam, the construction of 24 miles of canal, 7 miles of conduit to a reservoir at Lardner's Point, and steam-pumping machinery.

The distance would be 31 miles. The cost, with the expense of operating pumping engines, capitalized, would be $21,500,000.

Delaware by Gravitation.

The supply of water from the Delaware by gravitation, is the most popular of all the modes and sources suggested, by reason of the great volume and comparative purity of the water, particularly when considered where it passes through the mountains at the Water Gap.

No surveys or estimates have been made for a works which would take the water from a point of sufficient elevation to deliver it into the reservoirs of the city by gravitation; we are, therefore, without data upon which to form an estimate.

At Easton, 83 miles from the city, the river is but 164 feet above tide, so that, to be satisfactory, it would require a conduit of at least 100 miles in length. The work would involve a very large expenditure of money, and presents many engineering difficulties in the peculiar features of the country which would confine the line of the conduit almost entirely to the vicinity of the river; the fact that the stream has cut its way transversely through the mountain ranges which cross the state; the tributary streams, and the valleys formed by them, which it would be necessary to cross, and the difficulties such as would present themselves in the vicinity of Easton, etc. So that, financially, the burden would be too great for a city of 1,000,000

of inhabitants, unless this were the only source from which a supply of water could be drawn.

Perkiomen Creek.

The project of securing a supply of water from the Perkiomen, has never been in favor with the citizens generally, and notwithstanding it was presented to Councils in 1866, the Mayors, the City Councils, the Water Committee, the Chief Engineers of the Water Department and the Park Commission, have none of them been willing to assume the responsibility of recommending this source for a supply of water. The only public endorsement of the project is by the Commission of Engineers, in their report upon the future water-supply.

A large portion of their time was given to the investigation of the subject, and many pages of their report to a discussion of its merits. They also give plans and estimates for the construction of the work. Yet they have presented so many different suggestions, that, after all, we are not warranted in saying that they give it, or any other plan, a decided endorsement. They show it to be the best and most desirable source, and say of it, on p. 36 of their report: "In looking for a stream to furnish a gravity supply for Philadelphia, this tributary alone, of the many that flow into the Schuylkill, has been found to possess the proper requisites. Such a stream must possess a sufficient drainage area or water-shed; must not be too remote; must have a geological formation that will carry a good percentage of the rainfall to the reservoir; that will retain the water when impounded; and that will impart no mineral impurities. The region must be free now, and likely to remain free, from causes of pollution. A suitable site must exist for building a safe dam, and where a sufficient quantity of water can be impounded. *All these requirements are found to exist in the Perkiomen Valley.*"

With this exception, standing alone, so far as any public endorsement of this plan, let me ask your indulgence while endeavoring to present its claims somewhat at length.

The Perkiomen project is simply supplying the city from an artificial lake, fed by pure mountain streams. As presented to Councils, in 1866, it was as follows:

1. A lake or store-dam to be constructed where the trap-dike crosses the stream between Swenksville and Zieglersville.

The creek at this point has cut its way through the hills, which rise to from 400 to 500 feet above tide, and 200 to 300 feet above the bed of the stream. The trap-rock forms reliable foundation and abutment for the dam. This formation extends for a considerable distance across the country, and will form a complete barrier, preventing the water above it escaping. No better location could be desired than this for the constructing of a safe-dam of almost any desired depth and storage capacity. The one suggested in my report was to be 65 feet deep, and would cover 1500 acres with water, and would store 5,000,000,000 gallons, which could be used in time of drought, to make up deficiencies in the flow of the stream, or 100 days' supply for the present requirements of the city, if none was furnished by perennial springs or surface drainage.

2. A conduit to the city, to be constructed almost entirely of masonry, with a capacity of delivering 150,000,000 gallons per day.

Where pipes are used, as in case of inverted siphons, large saving in first cost could be effected by making them for a capacity of delivering 75,000,000 gallons per day, with the necessary arrangements for adding other pipes as the demands of the city made it necessary.

This conduit would be about 24 miles long, to a reservoir to be located in the upper part of the city. This reservoir to hold 1,000,000,000 gallons, to be constructed at some suitable site, with the water surface 170 to 185 feet above city datum, say, 75 feet higher than Fairmount Reservoir. Large feeding-mains to be led from the reservoir to various centres of distribution in the city.

The approximate estimates for the cost of the works were made without actually locating them, but were prepared after a survey and examination of the country between the Perkiomen and the city, and were liberal, so as to represent a sum that would be sufficient to meet all contingencies, and were as follows:

Lake or dam and land damages, . . .	$1,000,000
24 miles of aqueduct, at $250,000, . .	6,000,000
Store reservoir in the city, 1,000,000,000 gallons capacity, ...	1,000,000
Supply mains, to connect centres of distribution,	1,000,000
Contingencies, ...	1,000,000
	$10,000,000

The Commission of Engineers, in their report, give detailed estimates, with drawing, for a store-dam and conduit of much greater capacity. This was made by Wm. J. McAlpine, C. E., one of the Commission, an engineer of large experience in water-works construction. In this plan the lake or store-dam is to be made of such a depth as to cover 2,000 acres, and to allow the storage of 10,000,000,000 gallons; conduit, of a capacity for delivering 200,000,000 gallons per day; the estimated cost of the entire work is $10,860,730.

If the pipe-lines, and such parts as can be enlarged, are made with a capacity of but 75,000,000 gallons, and the permanent parts for 200,000,000, the works would cost, by this estimate, $6,782,172. Taking the present prices of labor and material, the works, as suggested by myself and presented to Councils, could be constructed for from $7,000,000 to $8,000,000.

This would enable the city to dispense with the small reservoirs, which, when considered as a part of the water-supply system of a great city, are of little consequence.

The pumping machinery of the various steam works, with much of the property occupied by them, could be sold. The value of these would make a large reduction in the actual cost of gravitation works.

The common objection urged to the Perkiomen, is that there is not enough water for the future demands of the city. The average amount of water supplied per day by all the works, in 1876, was 47,741,270 gallons. The daily average flow of the Perkiomen, as shown in my former paper, is, as per Commission of Engineers' Report, by Wm. J. McAlpine, C. E., 311,000,000 gallons. Calculated from data in Park Commissioners' Report, 250,000,000 gallons. My estimate, as presented to Councils in 1866, 240,000,000 gallons.

Taking the average of these, this stream will furnish more than five times the amount required for the present supply of the city.

The superior comparative purity of the source is also shown in the former paper. The Chief Engineer of the Water Department, in his last report, p. 14, says:

"Gravity and purity should be, and practically are, synonymous, and this mode becomes a necessity, if a pure, healthy water cannot otherwise be obtained." And again: "As all the conditions have been worked out and are known, as it applies to our own city, a com-

parison may clearly demonstrate why, as a matter of *purity, a gravity source is to be preferred;* while, as a matter of *economy, steam power* is our only plan, in the present financial condition of the city."

The facts presented in this paper demonstrate that in his conclusions the Chief Engineer has not considered all the elements of expense incident upon securing a prospective supply of water by steam-pumping; and it has been shown above, that, among the various plans suggested, there is none by which the future demands of the city can be met at less cost than by gravitation from the Perkiomen.

It needs no argument to demonstrate that the manner of enlarging the water-supply of a great city like this, as it has been done in the past fifteen years, by simply adding such facilities as the increasing demands make necessary from time to time—is not only a most expensive, but, when considered as a municipal improvement, most unsatisfactory.

The city has now 8 pumping-stations, 8 water-wheels, propelling 14 pumps, 16 steam-pumping engines, operating 25 pumps, 58 steam boilers, and 16 reservoirs at various heights.

If I have succeeded in showing that of all the plans suggested the Perkiomen gravitation project will secure an abundant supply of pure limpid water, at an increased elevation, and at a lower cost than any other of the schemes presented for a future water-supply of the city, and have thus made friends for a plan which seems to be a natural provision for our benefit, I shall feel that, in preparing and presenting these papers, I have done much to benefit the city we all love, and which deserves a purer and more copious water-supply than is now given to it.

The Lyons Globe.—There is said to be a terrestrial globe in the Jesuitic Library of the Lyons Lyceum, which is 170 years old, containing in great detail the curious system of African lakes and rivers, which the English and American travelers have lately re-discovered. It is two metres in diameter, and an inscription, near the north pole, states that it was made in the year 1701, by F. F. Bonaventure & Gregoire, Brothers of the Third Order of St. Francis. The globe has created a great sensation among geographical savans and amateurs, and it will probably be placed in the French Exposition.—*Les Mondes.* C.

ON THE EVIL EFFECTS ARISING FROM THE USE OF DOLOMITIC LIME IN BUILDING BRICK WALLS.

By Henry Pemberton.

In an able and recent paper by Mr. William Trautwine, published in the Journal of the Franklin Institute,[1] the author remarks that "the disfiguration of brick house fronts is now so general as to render it to the interest of brickmakers and builders particularly, that its causes may be determined and a remedy applied if possible." Mr. Trautwine shows that the ultimate cause thereof is the sulphur existing in the coal consumed in the processes of manufacture and of domestic life: the proximate causes, however, being twofold. First, the existence of silicate or other salts of magnesia in the brick-clay, converted into sulphate of magnesia in the process of burning in the kilns, by the sulphurous vapors from the coal. And, secondly, the employment of lime containing magnesia for the mortar used in the walls, which, by the absorption of the sulphurous vapors of the coal gases in the general atmosphere of the city, becomes converted into sulphate of magnesia, and being dissolved by the rain, penetrates the substance of the more or less porous bricks, effloresceing ultimately upon the surface.

Unsightly and disfiguring as this white efflorescence may be, it is, to the owner of the building, the index to a more serious evil, viz.: the disintegration of the mortar uniting the bricks, causing the destruction or fall of the chimneys and the washing-out of the joints, particularly in the back walls or gable ends of houses, where the bricks are irregular in size and the said joints are consequently thicker. The cavities and open joints thus produced facilitate the destruction, until the retained moisture penetrates the wall and compels the owner to refill or repoint the joints at a heavy cost—the whole proceeding probably to be repeated after a few years.

A careful consideration of all the facts connected with the above, shows that, although the salts of magnesia formed in the brick itself during the burning are sufficient to explain the first appearance of the white salts on its surface apart from any other cause, yet the

[1] Vol. CV, page 259.

amount thereof is too slight to account for the continued reappearance, inasmuch as the magnesia in the brick-clay seldom, if ever, exceeds the *one-half* of *one* per cent., and although this quantity, when converted into the soluble sulphate would be drawn by capillary attraction to, and accumulate upon, the surface of the bricks, yet, being washed off by successive rains, the supply from within would soon be exhausted, if not fed from some other source. Unfortunately, this source is abundantly found in the magnesian lime used in the mortar.

A curious contradiction exists between the statements of nearly all European writers as to the influence of the presence of magnesia in lime used for mortar, and the practical experience of builders with regard thereto.

It is generally taught in most text-books that the presence of magnesia is very injurious: thus Liebig's "Handwörterbuch" says: "Ten per cent. even of carb. of magnesia in the limestone is injurious." Rudolph Wagner, in his "Chemischen Technologie," Bd. i., S. 397, says: "The effect of ten per cent. of magnesia in the lime can clearly be seen in causing it to become 'lean' (*mager*). Twenty-five and thirty per cent. renders it perfectly useless!" Dr. G. L. Hogeboom, in the article "Cement," in the "American Cyclopedia," says: "When the proportion of carbonate of magnesia is forty-six per cent., the stone is called Dolomite, and has been pronounced unfit for making building-mortar. It does not become so hot or set so soon as a pure lime, but those who use it assert that in time it becomes *harder*."

The analysis of mortar from various sources, both ancient and modern, given by Spiller, in Muspratt's "Chemie," 3d Auflage, Bd. 3, S. 1542, shows that in Vienna the mortar used contains lime and magnesia in the ratios of from five to one to two to one, yet the statement of R. Wagner, above given, is copied a page or two before. This discrepancy arises, probably, simply from the fact, that workmen accustomed to the use of any special kind of lime, reject as unmanageable any other lime that requires a different manipulation, either in the act of making mortar or in laying brick therewith; thus local habits or prejudice will accept one material at one place as being merchantable and the best, that at another place will be rejected as worthless, and *vice versa*.

To the existence of this common trait in mankind, Philadelphia is largely indebted for the trouble in question.

Having had, some years ago, frequent occasion to examine into the composition of the lime used here for building and other purposes, I found that no lime available for chemical purposes would be accepted or used by builders. The latter using, without exception, a strongly magnesian lime, seldom, if ever, containing less than thirty per cent. of magnesia in the calcined lime, whilst lime for chemical purposes (most from limestone), containing over ninety-eight per cent. of carbonate of lime, is readily obtainable in any quantity within a few miles of Philadelphia, and is sold here at a lower price for agricultural and chemical uses than the ordinary builder's lime.

The character and necessary chemical behavior of these magnesian limes can be clearly seen by the following analysis I have lately made of fair average samples taken from the lime used in the block of handsome dwellings now being erected on the square of ground between Twenty-second and Twenty-third Streets, and Spruce and Pine.

It contains in 100 parts,

Lime,	57·18
Magnesia,	37·38
Silica,	1·19
Iron and Alumina,	1·03
Sulph. Acid (a trace only), Manganese, Alkalies, Carbonic Acid and Water,	3·22
	100·00

Or only 3·08 per cent. more lime than would be required for equal equivalents, or a perfect Dolomite.

That a cement composed of a substance, nearly one-half of which is readily attacked, dissolved and formed into a soluble salt, crystallizing with seven equivalents of water; or, in other words, of which every 100 lbs. of lime used contain enough magnesia to form 230 lbs. of Epsom salts or crystallized sulphate of magnesia—that such a cement *must* be disintegrated, washed out and destroyed, if the sulphuric acid required be furnished, is self-evident. That it *is* furnished we have ocular demonstration. That the destruction is not more rapid is surprising. The quantity of sulphuric acid (or rather sulphurous, ultimately becoming sulphuric) furnished by the coal

consumed in the city, is enormous. Some idea of it may be formed from the following observation: In preparing carbonic acid for chemical purposes on a large scale, it is usually obtained by the combustion of coal under steam-boilers and purification by washings, etc. To wash the gases resulting in twenty-four hours from the combustion, in said time, of 6000 lbs. of coal, yielding a gas containing from eight to ten per cent. of carbonic acid, a coke tower of eight feet in diameter by twenty feet in height was required, through which was passed, in fine spray, forty gallons of water per minute. This water, escaped from the tower at a temperature of about 110° Fahrenheit, consequently could retain but little carbonic acid, yet it permanently and powerfully reddened litmus paper, and was perceptibly acid to the taste. As this process ran continuously night and day, it showed that 6000 lbs. or three tons of coal rendered decidedly acid 480,000 lbs. of water. That most of the acid thus generated by the combustion of coal, is dissipated and lost in the atmosphere, is a matter of course, but enough must be caught by descending showers (or more effectively by mists and fogs) to cause apparently greater damage than we really sustain. No remedy can be applied to prevent or remove this production of acid. Our only recourse can be, therefore, to employ a lime free, or nearly free, from magnesia. Since the solubility of sulphate of lime is so slight (it requiring about four hundred times its weight of water, whilst sulphate of magnesia dissolves in twice its weight), it may be considered practically insoluble. Pure lime, as already stated, is abundant and cheap, but the prejudices of the workmen prevent its use. The behavior of a mortar made from magnesian lime is so different from that from pure lime as to render it easy to understand why the prejudice exists. Magnesian lime, in contradiction to most European authorities, forms, when slacked, a gelatinous, fatty mass, absorbing much water and permitting a large amount of sand to be mixed with it. The bricklayer, when using it, spreads out the mortar on the surface of the brickwork already laid as far as he can reach, without removing his feet from their position. He then places the brick in line upon this bed of mortar, placing as he does so, a little mortar on the end of each brick as laid, until perhaps seven or eight or more are in place, then points up the brick with the trowel on the face of the work. With *pure lime* mortar, this plan will not do. The mortar, when laid on the brickwork, becomes soon so firm—being less gela-

tinous or *pasty* than the magnesian—that two or three bricks only can be laid before it *sets* or becomes so dry as not to make a proper bond with the new brick and those already laid. Consequently, the bricklayer, accustomed to the magnesian lime, promptly and persistently rejects the pure lime as worthless, since he cannot execute the work expected of him in a given time, nor, probably, if used by him, would the bricks be securely and properly bedded.

That this is a local habit only, can be abundantly proved. In Pittsburgh, for instance, the only lime available is that from the limestone of the coal measures, containing only two or three per cent. of magnesia, or lime from the neighborhood of the "Sinking Valley," Tyrone, Hollidaysburgh, or other places near the eastern foot of the Alleghany Mountains. Throughout all this section, the lime produced and used is nearly free from magnesia, seldom if ever exceeding five or six per cent., and often less than one per cent. The bricklayers accustomed to it, know no other, and use it with entire satisfaction. No incrustation occurs there, notwithstanding the enormous consumption of coal in the city and immediate neighborhood.

The following experience may show still more clearly the influence of habit and accustomed ways upon those in the above trade. A few years ago, having occasion to erect large buildings in the suburbs of this city, in which more than a million bricks would be required, and having direct railroad communication with the west, by which lime produced in the neighborhood of Tyrone could be delivered from the quarries and kilns under my control, at first cost, cheaper than the ordinary lime used in the city could be carted, several car-loads were sent on. The lime being a nearly pure carbonate, with less than two per cent. of silica, iron and alumina, and about one per cent. of magnesia. Many millions of bricks had been laid with the identical lime in the west under my direction, in all sorts of constructions, from furnaces to dwelling-houses. On its arrival, in good condition, fresh from the kilns, it was slaked and mixed for mortar, but pronounced worthless and unfit for use by the workmen and master builder, notwithstanding the assurance given them that the same lime from the same quarries and kilns had been in constant use for years. On examination into the matter, it soon appeared that it would be cheaper to pay thirty per cent. more for such lime as the workmen wanted and were accustomed to, than to

force the use of the other lime, at the risk perhaps of an *emeute* between the bricklayers and their employers. The stonemasons found the same fault, viz., it set too quickly and they could not make good work with it. Its use was therefore abandoned and other lime substituted.

If the workmen from Alleghany county had been removed to Philadelphia, and those from Philadelphia to the former county, each party would have been dissatisfied with the new material furnished them. Experience of twenty years having shown the excellent qualities of the western lime for those who know how to handle it.

I have thought it might be of interest to present this grouping of facts and experiences, so that those who might wish to use pure lime in Philadelphia, as the proper preventive of the destruction of their walls and buildings, might know where to look for the cause of the past and present universal use of a bad building-material and the difficulties to be anticipated in supplanting it by a better one.

THE MICROPHONE.

Extract from the Secretary's Report at the meeting of the Franklin Institute, June 19th, 1878.

The discoveries recently made in relation to the laws of electricity and its application to useful purposes, have attracted more popular, if not scientific, attention than at any time in the history of that science.

Prominent among these is the articulating telephone of Prof. A. Graham Bell, which seems to have opened up an entirely new field in electrical investigation. This instrument is too well known to you (having been presented at the meeting in September last)[1] to need any further reference here, except to say that with all the inventions since made in connection with the telephone, the receiving instrument still remains, essentially, as first presented by him.

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[1] See Vol. CIV, page 219.

The next important discovery in this connection was by Mr. Thos. A. Edison, that carbon, properly prepared (in a finely divided state), possessed the property of changing its conductivity by pressure, and that the ratios of these changes correspond with the pressure brought to bear upon it.

This discovery is embodied in his carbon transmitter, presented here at the February meeting.[1]

Many modifications of, and some entirely new, transmitters were presented during the next few months, but no great step was taken until Prof. Hughes (also an American, although residing in England) discovered that when two or more electrical conductors rested lightly upon each other, the variations in the force of contact, caused by exceedingly feeble sonorous vibrations, would so vary the electrical resistance as to take up and transmit these vibrations, to the distant telephone, with great force and distinctness.

This discovery was first publicly presented in a paper read before the Royal Society, on May 9th last.

He started with the idea that variation in tensile strains would produce the same results as variations in pressure. As sonorous vibrations of a wire produced rapid variations of strains in its different parts, he placed a stretched wire in the circuit of a small battery and a Bell telephone. The wire was plucked, and the strains varied up to breaking, but no sound was observed until at the instant of rupture. He then sought to imitate the condition of the wire at the moment of breaking, by replacing the ruptured ends with a varying pressure, and found that if the ends simply rested upon each other, sounds made near them were distinctly reproduced. Further experiments soon showed that any two conductors placed in the circuit, in a similar manner, would produce the same result.

Thus two common nails, placed a short distance apart, and joined to the ends of the wire, and a third nail, or a piece of coin, laid across them, thus completing the circuit, would transmit delicate vibrations.

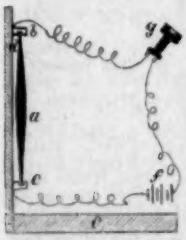
Prof. Hughes tried many substances, in a variety of forms, but that which seemed to answer best was willow-charcoal, treated by heating to a white heat, and plunged into mercury—thus filling its

[1] See Vol. CV, page 266.

pores with that metal. Gas-carbon was nearly as good, even without metallizing, and has the great advantage of not oxidizing.

The most sensitive form of transmitter is that shown in the figure, which he has named the Microphone, from its ability to magnify sounds. This consists of a lozenge-shaped piece of gas-carbon, *a*, one inch long, one-quarter inch wide at its centre, and one-eighth inch in thickness. This is sustained in an upright position by two small blocks of similar carbon, *b c;* resting on its pointed end in a small cavity in the lower block, its upper end playing freely in a like cavity in the other block. These carbon blocks are attached to any convenient support; in this case, a thin piece of board, *d*, nailed roughly to a heavier piece, *e*, forming a base. The form of the upright carbon is of no importance, provided its weight is only sufficient to make a feeble contact.

The amount of battery power necessary to operate the microphone is very small, any form answering the purpose. Indeed, very satisfactory results have been obtained by a battery composed of a copper cartridge case, one-quarter of an inch diameter, and half an inch long, filled with salt water, and a piece of zinc wire passing through the cork which closed the open end. In another case a voltaic pile was used, consisting of a copper cent and a piece of sheet zinc of equal size, separated by blotting paper wet with acidulated water.



The microphone is so sensitive that sounds quite inaudible to the unaided ear, are magnified so as to be distinctly heard. The vibrations caused by the fleshy part of the finger, or a narrow strip of tissue paper, drawn carefully along the face of the support, produce a distinct rushing or scratching sound.

Speaking in an ordinary tone, near it, causes a sharp, rattling sound in the receiving instrument, and, in order to transmit articulate sounds, it is necessary either to speak in a whisper, or at a considerable distance from it.

It must be remembered, however, that the sounds received by the ear are no louder than when the ordinary transmitter is used; but the microphone so increases feeble sounds that they may be uttered many feet away, and be as distinctly heard as when the ordinary transmitter is held near the mouth.

Its sensitiveness can be varied to a considerable extent, by inclining it to a greater or less degree; but, thus far, the most remarkable results have been obtained by leaving it in its most sensitive condition, and removing the source of sound to a distance.

Several microphones were exhibited, most of them of very rude construction, but answering equally well with the more finished instruments. Experiments were made to illustrate their exceeding delicacy. Sounds produced by the ticking of a miniature clock, the light twang of a very fine stretched wire, the movement of a small camel's hair-brush, and whistling in a low tone in a remote portion of the building, were transmitted and distinctly heard by members and visitors, through a number of Bell telephones connected in different parts of the lecture-room.

THE MICROPHONE RELAY.

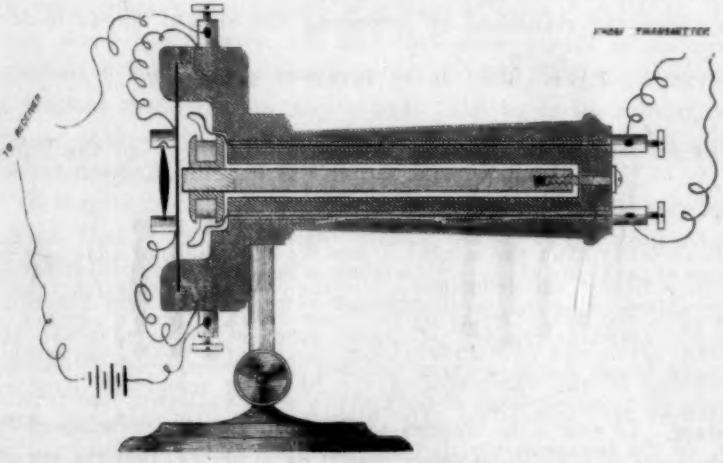
By Profs. EDWIN J. HOUSTON and ELIHU THOMSON, of the Philadelphia Central High School.

Immediately after the announcement by Prof. Bell, of his remarkable invention of the articulating telephone, the authors proposed for themselves the task of relaying this instrument. Quite a number of different arrangements were tried, but owing to the exceedingly feeble movements of the diaphragm of the receiving telephone, none of them were very successful. The discovery by Prof. Hughes, however, of the inexpressibly delicate microphone, happily afforded us the means of at last solving the problem at which we had been so long engaged.

In our application of the microphone for the relaying of the telephone, we attach a miniature microphone to the plate of the receiving telephone. The microphone so attached consists essentially of three small pieces of carbon, each being about $\frac{3}{4}$ of an inch in length. These pieces are arranged exactly as in the manner described by Prof. Hughes, viz.: one of the pieces of carbon, which is sharpened at both ends, rests vertically in small cavities near the ends of the two other pieces, as shown in Fig. 1. The two carbon supports for the third piece are cemented at their ends directly to the plate of the telephone.

The microphone so constructed is placed in the new circuit in which it is desired to repeat the message originally transmitted. The method of its operation is evident. The slight movements of the diaphragm of the receiving telephone, which are, in fact, so slight as to render them almost impossible of detection by mechanical means, are nevertheless at once recognized by the marvellously sensitive microphone, and are repeated in the new circuit as variations in the intensity of the electrical current traversing it. The message so relayed or repeated, for it is evident that the instrument can be used either as a relayer or a repeater, may be either received at once by a telephone placed in said circuit, or may be again repeated

Fig. 1.



in a new circuit. By this means we believe that the distance to which a telephone message can be transmitted will be very greatly increased.

Owing to the extreme sensitiveness of the microphone, it will be necessary, in the practical application of this instrument as a relay, to carefully shield it from all extraneous sounds, which, weak though they may be, are, nevertheless, very loud when compared with those which would be produced by the feeble movements of the plate of the receiving telephone. This may be obtained in practice in several ways; as, for example, by placing the microphone relay in a box with double or treble hollow walls lined with cotton, wool, or some other non-homogeneous material; or by sinking the instrument in a pit

under ground. We have found but little difficulty, however, in the trial of our instrument over a city line of some three miles in length, of obtaining the quiet necessary for the working of the instrument, although the latter was placed in a large room in the second story of a building facing a public thoroughfare, and the time of trial was shortly after midday.

The microphone, when properly constructed, has its greatest sensitiveness when the piece of carbon pointed at both ends rests in a nearly vertical position. Its electrical resistance is then at its maximum. In this position the upright carbon is resting on its extreme ends, and the cross-section of contact a minimum. So placed the slightest acoustic movement brings portions of the conical surfaces of the upright piece against the edges of the cavities, and thereby diminishes the resistance by increasing the area of the surfaces in

Fig. 2.

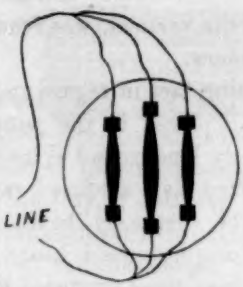
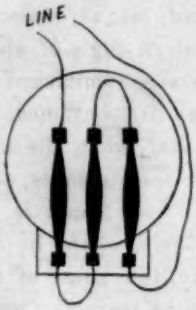


Fig. 3.



contact. If now it be desired to diminish the sensitiveness of the instrument, it is only necessary that it be so placed, that the upright carbon be no longer supported vertically, but be slightly inclined In this position more force is required to move the upright piece, and so cause it to vary the electrical resistance. In all the microphones that we have experimented with when the upright piece was held nearly vertically, whispers or other faint sounds were distinctly transmitted, but the voice of a person standing a few feet from the instrument, and speaking as in ordinary conversation, caused such a rattling of the receiving instrument as either to render the sound unintelligible or greatly confused. In all such cases, a certain inclination could be obtained, varying slightly in each instrument, at which the rattling of the instrument entirely disappeared, and the sound was distinctly and loudly transmitted.

When the microphone relay is placed in a circuit whose resistance is considerable, as, for example, at the end of a distant station, we increase the sensitiveness of the instrument by attaching a number of minute microphones to the receiving diaphragm, as shown in the figures. These may be connected in series to separate battery circuits, as in Fig. 2, or in multiple arc in the same circuit, as in Fig. 3.

Since the variation in the electrical resistance of the microphone depends mainly on the upper contact of the loose piece with its support, an increased delicacy may be obtained by attaching this support directly to the middle of the diaphragm of the receiving instrument, while the lower support need not necessarily be attached to the diaphragm.

We have measured the resistance of a microphone, in which the movable piece was composed of a piece of carbon about 1¼ inches long and ¼ inch square, and find that when placed in an upright position, it has about a resistance of 50 ohms, varying, however, in a marked manner, with any sound. The same instrument, when turned at an angle of about 40° from the vertical, was found to have its resistance diminished to about 25 ohms.

It may be mentioned, as an interesting fact in regard to the microphone, that when the upright piece is placed in the position of its greatest sensitiveness, and a moderately loud sound is made near it, although such sound is only transmitted as a confused rattling, yet its resonance can, in most cases, be distinctly heard. This is, probably, the cause of the peculiar ringing sound heard when the microphone transmits mere noises, such as those produced by a person walking.

Microphone.—Du Moncel, in describing Hughes' microphone, reported some experiments of Crookes, who compared the sound of a fly enclosed in a box to the kicking of a horse. When a watch was placed upon the table, the play of the wheel-work, the strokes of the balance-wheel, and even the special sound of the metal, were all heard distinctly. Hughes is said to have transmitted, by means of his system, the most minute sounds to a distance of one hundred miles. Carbon is not the only substance which can be employed; he has obtained very good results from iron, and the effect produced by surfaces of platinum, in a great state of division, has been equal, if not superior, to that which has been obtained from the mercurized carbon.—*Comptes Rendus.* C.

Phosphorus in Iron and Steel.—Melted pig iron and iron oxide, melted in a cupola, are mixed together, by Bell, in a revolving puddling furnace, at a moderate temperature, when the phosphorus oxidizes before the carbon has been absorbed. The purified iron is then withdrawn into a furnace, in which it is changed into wrought iron or steel.—*Ber. Deutsch. Chem. Ges.* C.

Propagation of Electricity and Heat.—Cornu has investigated the application of Fourier's formulæ relative to the diffusion of heat to the propagation of electricity. He finds that there are, under certain conditions, phenomena which may be represented as electric waves moving with a constant velocity, but that there is another phenomenon, which he calls the diffusion of electric waves, which seems to vary with the simple distance rather than with the square of the distance.—*Comptes Rendus.* C.

Tale-telling Gas Tubes.—M. Izarn, at the Lycée of Clermont, noticed that he was able to hear the Morse signals from the Telegraphic Bureau and from the Artillery School, although there were no wires near enough to account for the fact. He found that there were gas tubes in the neighborhood, and he supposed that the message was conveyed by a derived current, through the intervention of the moist soil and a net-work of tubes. He satisfied himself by experiment that the phenomenon could not be explained by the telluric currents, and suggests the importance of taking proper precautions to prevent the secrets of the telegraph from being exposed in this unexpected way.—*Comptes Rendus.* C.

Influence of Light upon Cement.—Dr. Heintzel thinks that the influence of light upon cement has not hitherto been sufficiently considered. He instituted some experiments upon a quantity of cement, which he divided into three parcels, exposing parcel A to the air and full light, B to the air and diffused light, and secluding C in darkness from the air. After six months he found that A made a weak mortar, by absorbing 38 per cent. of its weight in water, and it had become crumbly; B, with 33⅓ per cent. of water, made a mortar which was too adhesive to the trowel, and it yielded up none of its water; C, with 33⅓ per cent. of water, made an excellent mortar, easily stirred and flowing, and it relinquished some of its water. After setting for twenty-eight days, the relative strength was: A, 3; B, 37·9; C, 44·6.—*Ding. Jour.* C.

Earth Currents.—Du Moncel objects to the term "telluric currents," because the currents during the day are inverse to those which are produced during the night. During the day they are directed from the telegraph line to the earth and are thermo-electric. During the night they have an opposite direction, because the dew cools the wire and produces an increased oxidation which makes the currents hydro-electric in their character.—*Comptes Rendus.* C.

Objections to "Hard Glass."—A. Lamek (*Polyt. Notizblatt*) warns chemists against the use of beakers, alembics, and other articles made of "hard glass." He was filtering a solution of phosphate of lime into a half-litre glass, when it suddenly exploded, without any perceptible cause. He had not heated the glass, neither was there any shock or change of temperature, but the glass was "shivered into a million fragments," and he was wounded in the back. C.

Defective Notes of Stringed Instruments.—Achille Dien has sent two memoirs to the French Academy, the first upon the defective notes of violins and similar instruments, and the second upon the resonance of the minor seventh, in the heavy strings of the piano. He shows that the defects are owing to secondary vibrations which are set up either by the bow or mufflers. He counteracts them by a third system of vibrations, which neutralizes the discord so effectually that the Academy has given its approval to his inventions.—*Comptes Rendus.* C.

The Equivalent of Gallium.—Boisbaudran has estimated the value of the equivalent of gallium: 1. By calcining gallo-ammoniacal alum; 2. By calcining the nitrate of gallium which is formed by a known weight of metal. The small losses of material during these two operations affect the value of the equivalent inversely, so that the mean is not perceptibly changed. His investigations lead to a maximum value of 69·97, and a minimum of 69·66, giving a mean of 69·82. After making various comparisons among the spectra of aluminium, gallium and indium on the one side, and sodium, rubidium and caesium on the other, he deduces the value 69·86, which is a little greater than that which was given by Mendelejeff for the body which he predicted, in his theoretical classification of the elements.—*Comptes Rendus.* C.

Submarine Lighting.—Barnet and Foster compress pure oxygen into a cylindrical reservoir of forged iron, under a pressure of thirty atmospheres. This oxygen is supplied by a flexible tube to an alcohol lamp provided with means for the escape of the gaseous products of combustion. This furnishes a brilliant light for a period of four hours. Heinlhe and Davis use a glass cylinder upon the diver's helmet, which contains an electric lamp of polished copper. The carbons are arranged to last for about four hours without being renewed. The whole apparatus weighs about 27 kilogrammes, and is capable of furnishing a light equivalent to 20,000 standard candles.—*Rev. Marèt.* C.

Transit of Mercury.—Among the reports of the transit which have been communicated to the French Academy, those at Ogden seem to have been the most satisfactory, sixty-eight photographs having been taken. At Montsouris the day was cloudy, and only partial glimpses of the sun could be obtained. They were, however, sufficient to show a remarkably close accordance with the predictions of the French *Connaissance des Temps.* At Toulouse, the aureole was noticed at three different times, but always without the black glass, when the thickness of the clouds allowed only a small quantity of light to escape. Great satisfaction is expressed at the confirmation of Leverrier's theory of an intra-mercurial planet, and it seems to be generally admitted that the aureole is due to terrestrial atmospheric influences.—*Comptes Rendus.* C.

Ratio of Draft to Mean Temperature.—Palamede Guzzi has investigated the mean temperature of the smoke in chimneys, and the force of draft which arises from it. By means of a manometer of special form he weighs the volume of smoke in the chimney, and thus deduces its density and temperature. He finds the formula

$$\frac{\tau_0+\tau_1}{2}=\frac{H\,\tau}{H-0{\cdot}002927\,.\,\delta\,.\,\tau},$$

in which H is the height of the chimney in metres; τ_0, τ_1, the extreme temperatures in the chimney; τ, the absolute temperature of the external air; δ, draft force, at the foot of the chimney, in millimetres of water. The greatest difficulty in the application of the formula is in the determination of δ, which may be found by extended experiments upon boilers of different types and sizes.—*Il Politecnico.* C.

Hardening of Copper and Copper Alloys.—Everitt gives the following recipe: Melt together and stir until thoroughly incorporated, copper, and from one to six per cent. of manganese oxide. The other ingredients for bronze or other alloys may then be added. The copper becomes homogeneous, harder, and tougher.—*Berg- u. Huett. Zeit.* C.

New Electric Lamp.—Reinier has exhibited a new electric lamp to the French Academy, in which he uses a small bar of carbon pressed laterally by a moving elastic contact, upon a fixed contact, and crossed by a moderate current between the two contacts. It gives clear white light with four Bunsen elements. With more powerful sources of electricity, many lamps can be kept burning, and the electric light can thus be readily divided.—*Comptes Rendus.* C.

Limits of Gaseous Combustibility.—P. Schutzenberger has experimented upon the combustibility of various mixtures of oxygen and hydrogen, or hydro-carbons. He finds that the completeness of the combustion depends upon a large number of elements, viz: the proportion of the gases, the pressure, the length of the column of gas submitted to the spark, the diameter of the tube, the initial temperature of the gas, the force, magnitude, and position of the spark, the dryness of the gas. He finds a marked tendency to nodes, dividing the column into two or four equal parts, across which the combustion can pass only with difficulty.—*Soc. d'Encour.* C.

Complementary Colors.—Chevreul has lately communicated to the French Academy some experiments upon the influence produced upon the appearance of colored objects which are rotating, when they are compared with similar objects in repose. He considers them as confirming all the experiments upon which he founded his laws of simultaneous, successive, and mixed contrasts of color. At a time when the industrial and fine arts have found the necessity of testing the susceptibility of their apprentices to delicate shades of color, and especially when the science of signalling is assuming so great importance, he considers that such experiments deserve special attention, and suggests that by means of spinning tops, very delicate and ready tests can be provided.—*Comptes Rendus.* C.

St. Gothard Tunnel.—A singular depression has been lately noticed in the strata which are traversed by the St. Gothard Tunnel. Some geologists think that it indicates a subterranean sea in the interior of the mountain. A late report of the inspector of the works asserts that the irregularity has ceased, and the perforation has resumed its regular course. On the southern side there is an advance of three metres per day. It is a little less at the northern extremity, where the tunnel has not yet emerged from the serpentine, although it has traversed that hard rock for double the distance that the geologists anticipated.—*Les Mondes.* C.

Music and Acoustics.—Helmholtz, Blaserna, and some other eminent savants, have thought that there might be an advantage in confining music to exact combinations, and in renouncing the temperaments adopted in musical practice. Helmholtz even made a harmonium, so constructed that he could play, at will, either with the scientific or with the tempered scale. Although he obtained some remarkable results in the scientific gamut, Hirn opposes a change which would so greatly reduce the resources of the art. He enters upon an inquiry whether science can explain the powerful action which sounds and their musical combinations produce upon us. Faye regards this novel investigation as one of profound interest, and proposes to extend it to the Oriental and other forms of music, which are founded upon principles entirely different from our own, without diminishing their action on the human organism.—*Comptes Rendus.* C.

Submarine Telephone.—The first use of the telephone under water in this country has been recently made, in connection with submarine examinations in Boston Harbor. The character of these examinations was such that it would have been impracticable to undertake them without its aid, as almost constant communication was necessary between the diver and his assistant in the boat. The telephone used under water has a metallic case so modified in form as to occupy but little space, and is attached by screws to the inside of the diver's helmet in such a position that either the ear or the mouth can be applied to it. In the boat, a single telephone of the ordinary form is used. The insulated copper wire connecting the two telephones passes through the air-pump box. Between the pump and the diver's helmet it is wound spirally around the air hose, the wire

and hose being then tightly wound around with canvas for protection from injury. At first two connecting wires were used, the second not necessarily insulated, but it has since been found better to substitute for the second wire a shorter wire connecting the upper telephone with a copper plate fastened under the boat.—*Engineering News.*

Book Notice.

HOUSE DRAINAGE AND WATER SERVICE IN CITIES, VILLAGES AND RURAL NEIGHBORHOODS, with incidental consideration of causes affecting healthfulness of dwellings. By James C. Bayles, Editor of the *Iron Age* and the *Metal Worker*. Large 8vo., pp. 360. Price, $3.00. David Williams, N. Y., 1878.

This work takes up the subject of drainage and water-supply where the professional engineer usually leaves them, and treats more particularly of those points which are under the control of the individual house-owner, and those connected with the house-building trades, touching only incidentally upon the subjects of town drainage and public water-works. It is not in any sense a manual for the plumber, but it is a clear and full exposition of the hygienic principles involved, and of the best modes and materials to be used in maintaining the healthfulness of our dwellings.

Chapter I treats, in a general way, of Hygiene in the practical relation to health, pointing out the fearful ravages of diseases in the middle ages, arising from a disregard of the simplest requirements of health, and shows that with the great progress since needed, sanitary science is still in its infancy.

Chapter II discusses the production and nature of *sewer gas*, its action in producing disease, and the different theories upon the subject of sewer gas poisoning. The importance of sewer ventilation is forcibly considered, together with the methods employed for that purpose.

The next five chapters treat upon the mechanical portion of the plumber's trade, and cover every detail of pipes, traps, seals, tanks, closets and household fixtures, with numerous examples of the most approved practice, and some of bad practice.

Great stress is laid on the importance of properly arranging all these connections of the water-closet, and eighteen pages are given to that subject alone.

Chapter VIII, on the Chemistry of Plumbing, is a valuable contribution to sanitary science, containing a discussion of the action of

the various substances found in solution in water; on the materials used in plumbing, and of the best known methods of preventing results deleterious to health.

Chapter IX, on Elementary Hydraulics applicable to plumbing, contains some tables and other information in regard to the pressure and flow in pipes, and the raising and storing of water, calculated to be of great use to the practical plumber.

The next two chapters, on Sanitary Construction and Drainage of Country Houses; water-supply in country districts, particularly deserve the attention of those living in districts remote from public drainage and water works.

Chapter XII, on the Sanitary Care of Premises, treats mainly on cleanliness, and on the nature and use of disinfectants, and pertains more to housekeeping than to plumbing.

Chapter XIII, on the Plumber and his work, discusses the relation between the plumber, and the architect, the builder and the householder, and, in a certain sense, is a plea for the former. While pointing out many of the shortcomings of the practical plumber, he also shows that the fault does not lie entirely with him, but that each of the others is responsible in a considerable degree in bringing about a condition of affairs which give us much inferior plumbing work; cheap, perhaps, in dollars, but fearfully expensive in health.

The thorough and comprehensive character of this work must commend it to all interested in the mechanics of hygiene.

The mechanical execution is excellent, being printed on heavy tinted paper, in clear type, with good illustrations; and a copious index renders the contents readily accessible to the reader. *

Franklin Institute.

Hall of the Institute, June 19th, 1878.

The stated meeting was called to order at 8 o'clock P. M., the Vice-President, J. E. Mitchell, in the chair.

There were present 206 members and 77 visitors.

The minutes of the last meeting were read and approved.

The Actuary presented the minutes of the Board of Managers, and reported that at the last meeting 2 persons were elected members of the Institute; and the following donations made to the Library:

Pennsylvania Archives, Second Series. Published under direction of M. S. Quay, Secretary of Commonwealth. Edited by John B. Linn. Vol. 6. 1877. From Hon. J. B. Linn.

Reports of Commissioner of Patents, U. S. Patent Office. Mechanical, 1849-50, 1855, Parts 1 and 2; Agricultural, 1851, 1854, and 1856. From W. P. Tatham.

Sketch of the origin and progress of the U. S. Geol. and Geog. Survey of the Territories. Wash., 1877
From F. V. Hayden, Geol. in Charge.

Geological Survey of Hokkaido; a general report on the Geology of Yesso; by Benj. S. Lyman. Tokio, 1877. From the Author.

Iron-works of the United States; a Directory of the furnaces, rolling mills, etc. Phila., 1876.
From the Am. Iron and Steel Asso., through E. Hiltebrand.

Bulletin of the U. S. Geol. and Geog. Survey of the Territories. No. 1, Vol. 4. Wash., Feb. 5, 1878.

Report of the U. S. Geol. Survey of the Territories. F. V. Hayden, Geol. in Charge. Vol. 7, Tertiary Flora, by Leo Lesquereux.

U. S. Geog. and Geol. Survey of the Rocky Mountain region. J. W. Powell in Charge. Vol. 3, Contributions to North American Ethnology, by S. Bowers, Wash., 1877.
From the Secretary of the Interior.

Pennsylvania and the Centennial Exposition: comprising the preliminary and final reports of the Penna. Board of Centennial Managers, made to the Legislature, at the sessions of 1877–78. 3 parts in 2 vols. Philadelphia, 1878.
From Am. Iron and Steel Asso., through E. Hiltebrand.

Annual report of the operations of the United States Life-Saving Service, for the fiscal year ending June 30th, 1877. Washington, 1877. From Secretary of the Treasury.

Sixth annual report of the Board of Directors of the Zoological Society of Phila., read April 25th, 1878. From the Society.

Salisbury Iron. Its composition, qualities and uses. Barnum Richardson Company, 1878. From the Company.

Almanaque Nautico para, 1875. Calculado de orden de la superioridad en el Instituto y observatorio de marina de la Cindatt de San Fernando. Madrid, 1878. From the Observatory.

Classified and descriptive catalogue of the collection of the Products and Manufactures of British India. Compiled by J. Forbes Watson, Philadelphia. From the Penna. Museum and School of Industrial Art.

Specifications and drawings of patents, issued from the United States Patent Office, for November, 1877.
From the U. S. Patent Office.